JOURNAL OF THE A·I·E·E·

MAY 1925

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Annual Convention, Saratoga Springs, June 22-26

Pacific Coast Convention, Seattle, Wash., September 15-17

Regional Meeting, District No. 1, Swampscott, Mass., May 7-9

MEETINGS OF OTHER SOCIETIES

The American Society of Mechanical Engineers, Spring Meeting, Milwaukee, May 18-21; Regional Meeting, Portland, Ore., June 22-25

Middle West Division, N. E. L. A., Hotel Fontenelle, Omaha, Neb., May 20-22; Iowa Section, Waterloo, Ia., June 3-4

Georgia Electrical Association, Atlanta, May 21-22

American Association of Engineers, Orlando, Fla., June 2-5

National Electric Light Association, San Francisco, June 15-19

Northwest Electric Light & Power Association, (Geographic Division, N. E. L. A.) Gasco Bldg., Portland, Ore., June 12

Pacific Coast Electrical Association, (Geographic Division, N. E. L. A.) San Francisco, June 15

Society for the Promotion of Engineering Education, Union College, Schenectady, June 17-20

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Phillipines, $10.50 to Canada and $11.00 to all other Countries. Single copies $1.00.

Entered as matter of the second class at the Post Office, New York, N. Y., May 10, 1905, under the Act of Congress, March 3, 1879. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918.

Vol. XLIV — MAY, 1925 — Number 5

TABLE OF CONTENTS

Papers, Discussions, Reports, Etc.

Institute and Related Activities

A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any change in business connections.

Current Electrical Articles Published by Other Societies

American Electrochemical Society—Advance opy, April, 1925
Electromagnetic Forces Available in Electric Furnaces, by C. Hering

Journal of the American Welding Society, March, 1925
Electric Power Supply to the Welding Industry, by C. W. Bates
Welding Cast Iron with Bronze, by S. W. Miller

Agricultural Engineering, March, 1925
Demonstration of an Electric Farm, by R. U. Blasingame and E. Grant Lantz

Engineers Bulletin, February and March, 1925
Suggestions for New Rules in Electrical Installations, by D. J. McDougall

Transactions, American Institute of Mining Engineers, March, 1925
Determination of Suspensoids by Alternating-Current Precipitators, by P. Drinker and R. M. Thomson

Transactions, Illuminating Engineering Society, February, 1925
Daytime Illumination in Show Windows, by W. Harrison and W. Sturrock
Display Case Lighting in Stores, by J. L. Stair and W. Foulks

March 1925
Glare and Visibility—A Resume of the Results Obtained in Investigations of Visual and Lighting Conditions Involving These Factors, by M. Luckiesh and L. L. Holladay
The Meaning of "Speed of Vision," by P. W. Cobb
Ocular Principles in Lighting, by C. E. Ferree and G. Rand
Periodic Eye Examinations in a Testing Laboratory, by N. D. MacDonald and J. W. Smith
Short Cut Design for Electrical Advertising, by C. A. Atherton

Iron and Steel Engineer, March, 1925
Cutting Steel Mill Maintenance Costs with the Welding Arc, by A. M. Candy
Electric Arc Welding in the Steel Industry, by W. L. Warner
Essentials of Design of Electric Industrial Furnaces and their Application to Leveling up Load Curves, by G. P. Mills, (with discussion)

Journal of the Franklin Institute, March, 1925
Ampere Trough Experiment and its Explanation by the Usual Electromagnetic Laws, by F. W. Grover and others

Journal of the Western Society Engineers, February, 1925
A Survey of Current Progress in Radio Engineering, by J. H. Dellinger

Mechanical Engineering, April, 1925
Ramsay Condensing Turbo-Electric Locomotive, by G. F. Jones and T. L. Hale

Bulletin National Electric Light Association, March, 1925
Exploding Some Myths on Superpower and "Giant Power," by A. Dow
Farm Electrification in Michigan, by E. Holcomb
Industrial Electric Heating—Its possibilities and Promise, by F. A. Coffin

Military Engineer, March-April, 1925
Construction of Joint-Pole Circuits, by A. E. Ransom

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLIV MAY, 1925 Number 5

More Electrical Usefulness

The broadening of the field of electrical application is evidenced on every side. In looking over papers presented at Pasadena in October, at New York in February, and in April at St. Louis, it is easy to recognize the new comers, fresh from the advance lines of new application. The engineers of the industrial world have been so busy with their own individual problems that we have heard little from them in our Institute forum, but now that their preliminary work is behind them, we shall be hearing more and more of their doings.

It is refreshing to learn of entirely new applications, based on the old fundamentals, bringing us to a realization of the fact that the horizon of possibility is being pushed forward to a point beyond the vision of man today.

Welcome are these new authors, and it is hoped that the engineers of the marine, mining and all industrial fields, will feel their value to Institute activity is great and their duty to orient their work at our meetings, is real.

FARLEY OSGOOD

The St. Louis Discussion

The character of the discussions presented at Institute Conventions has been improving recently with each successive meeting, and the discussion at the St. Louis Convention was, in general, as pertinent and valuable as could be desired, and was notably free from irrelevant digressions. In years past it was not uncommon for a speaker to announce that he was not prepared to discuss a paper, as he had not had an opportunity to read it, and then continue to discuss at considerable length that which he thought might be in the paper. Such discussions generally hit wide of the mark, and, in some years, the result was the elimination of 50 to 60 per cent of the verbal discussion in the printed records. No such abridgment of recent discussions has been necessary or even desirable, and it is probable that the St. Louis discussion will be published practically in full. This type of discussion not only makes the meetings and printed records interesting and valuable but conserves much labor in subsequently separating the wheat from the chaff.

Several reasons for the recent improvement in discussions might be enumerated, but there are probably three outstanding ones that have contributed largely to this result. First, the Meetings and Papers Committee has been extremely careful, in selecting programs, to assign to a certain locality papers on subjects which are live issues in that locality and hence arouse wide local interest. This plan is followed as far as is compatible with the necessity of providing a sufficiently variegated program.

Second, a strong effort has been made to furnish advance copies of papers as early as possible. Lately advance copies of most of the papers have been available for distribution a week or two in advance of their presentation, and while this is not possible in the case of every paper, the practise of early printing is being pushed to the limits of the Institute's publishing facilities.

Third, there has been a noticeable tendency at recent meetings for members to prepare written discussions, which in the vast majority of cases are much better finished products than the spontaneous verbal discourses. In this connection, the Convention Committee at St. Louis introduced an innovation by supplying stenographers and typists for the convenience of members desiring to submit written discussions. The number of members who availed themselves of this service points to the desirability of adopting this practise for future conventions.

Some Leaders of the A. I. E. E.

Charles P. Steinmetz, the fourteenth president of the Institute, was born in Breslau, Germany, April 9, 1865. His early education was gained in the local schools of his home city. At the University of Breslau he specialized in mathematics, astronomy, physics and chemistry. In 1888, he studied mechanical engineering at the Zurich, Switzerland, Polytechnikum.

In the year 1889, he came to New York and procured a position as draftsman with the Osterheld and Eickemeyer Manufacturing Company, Yonkers, N. Y., manufacturers of electrical apparatus. In the service of this company he was promoted to electrical engineer, and later, to research engineer.

In the year 1893, the Eickemeyer Company was absorbed by the newly formed General Electric Company. Dr. Steinmetz continued with the General Electric Company for a period of thirty years, until the time of his death.

He was first employed at Lynn, Mass., in the calculating department, a year later removing to Schenectady, N. Y., where he was placed in charge of the design of the company's apparatus, its research and development work. Subsequently he was appointed chief consulting engineer, and about the year

1910 was given a special engineering organization with complete facilities for independent research work.

His masterly mathematical analyses of alternating-current problems brought about wide extensions in the use of alternating-current machinery and power systems, Dr. Steinmetz was granted more than two hundred patents covering a wide range of electrical inventions.

From the year 1902, Dr. Steinmetz maintained connection with Union College, Schenectady, first as professor of electrical engineering, and later as professor of electrophysics.

In the year 1902, he received the honorary degree of A. M. from Harvard University, and the following year the honorary degree of Ph. D. from Union College.

Dr. Steinmetz early gained note as a writer on technical subjects, through papers presented before the A. I. E. E. He was the author of a great number of papers on various phases of electrical engineering, and of ten important books, several of which were republished from time to time in later editions.

Dr. Steinmetz was president of the A. I. E. E. throughout the term 1901-1902. He was president, also, of the Illuminating Engineering Society, and of the National Association of Corporation Schools, and was a member, or honorary member, of many American and foreign scientific societies and associations.

A Practical Program

The Institute convention in St. Louis was notable for the diversity of topics treated and for the practical values of the papers and discussions. With the very large A. I. E. E. membership, it seems fitting that convention programs should give something of value to all members, and the practical features of engineering interest a large number. The Midwinter Convention program consisted of advanced technical papers for theoretical specialists, but the St. Louis meeting was adapted very largely to operating engineers.

Economies in electrical production, developments in motors and power systems, problems of personnel, equipment in marine work, new equipment in communication and electrical applications in mining and general industry were discussed before a large audience of Institute members. The papers were of a high grade and presented the developments made and the problems still to be solved before electricity can reach 100 per cent efficiency in application. Just as much good engineering is required in applications as in researches; and often more, for an application engineer must deal with men, money and materials in addition to technical principles.

Another feature of the meeting was the noticeable trend toward a greater participation of the Institute in national affairs. Here it can do good service by making impartial investigations and publishing the facts on many national problems having an electrical engineering background. One more point deserves comment. The policy of building up recognition for electrical men in marine work announced at the convention is a notable example of the constructive work the Institute can do.—*Electrical World.*

The Part of Superpower

We hear much today of superpower besides a considerable dash of emphasis given to "Giant Power" in the State of Pennsylvania. As neighboring utilities reached out into new fields, their outposts naturally came within close range of one another and it was early apparent that a tie-in between their exterior lines would vastly improve the service to such outlying points. There followed from this embryonic stage the conception of a substantial interconnection which would economize in reserve capacities to be installed and maintained by the two independent systems and also permit further savings where a difference in load characteristics existed between the two properties. A third step in the progress of this "Inter-Utility Service," as it may be appropriately designated, was the expansion of the facilities of the company most favorably situated as to fuel supply and condensing water to furnish the requirements of its neighbor in full or in part.

A distinction has been attempted between so-called "Giant Power" and "Superpower." In the last analysis, there is no real difference outside of the terminology employed. "Giant Power" has been used to designate the final development in inter-utility service and the mere fact of a name should not mislead us into believing that a new departure in central station economics is about to be introduced. History of the electric utilities is replete with evidence of bold and heroic ventures embracing new and unexplored fields which aided in developing the many advantages now obtaining through this public service. There can be no doubt that the greatest amount of progress will ensue where an incentive exists for private undertaking and where there is reasonable freedom of action permitting the exercise of prudent judgment.

Interconnections of sizable extent are now an accomplished fact. By voluntary action, public utilities are now virtually linked together from Boston to Chicago and beyond, from Lake Erie to the vicinity of Baltimore, from Virginia to Southern Alabama and along the entire Pacific Coast. These are examples of the strides which have come through the exercise of private initiative. Large trunk lines of high voltage have been established and mammoth power stations have been jointly built by neighboring utilities. Thus superpower or "Giant Power," if you choose to call it by such terms, has for sometime passed from the visionary stage to that of present-day reality.—E. D. Dreyfus in *N. E. L. A. Bulletin.*

Communication in Railroad Operation

BY I. C. FORSHEE[1]

Associate, A. I. E. E.

Synopsis:—*The object of this paper is to show the part played by the different means of electrical communication in operating a large railroad system. The telegraph, which was the original and sole means of handling communications requiring immediate attention, has given way largely to the telephone and the printer. The development of the selector was essential to the general use of the telephone for train operation and message work, the train wire being considered the most important circuit in railroad operation.*

Extensive and special facilities are required in some instances to provide necessary telephone communication with the public. This includes telephones on certain limited trains in terminals.

The telautograph is important but limited to local service in terminals and junction points.

Same problems in engineering, construction, maintenance and operation as with the commercial telegraph and telephone companies, except that smoke conditions are worse along the railroad and continuity of service is possibly more important.

Radio has possibilities as a means of providing information and entertainment to passengers on trains and in the operation of freight trains and tug boats.

In handling train orders the train conductor must verify the instructions or orders he receives. The quality and accuracy of radio reception when a train runs through rock cuts, over or under certain types of steel bridges, through tunnels and during certain weather conditions prevents this means of communication from being used at this time for handling train orders.

The volume of communication traffic is affected by the seasons, holidays and emergencies.

The size of the communication system on some railroads compares favorably with that of some of the large commercial telegraph and telephone companies.

An ideal communication system would provide accurate information between any two points on a railroad system or between the public and the railroad company without delay and under all operating conditions.

THE means of communication which will be referred to in this paper includes the telegraph, telephone, telautograph, telegraph printers and radio.

The signal system used in connection with the movement of trains, which includes the various hand operated or manual signals, and automatic signals of the different types such as semaphores, colored lights and position lights, as well as train control systems, in reality form an important part of a railroad communication system, as they convey information to the enginemen or trainmen regarding the condition of the track ahead. This will not be included in the present paper.

TELEGRAPH

Train Operation. The handling of train orders by telegraph was started in 1850 and was used more or less extensively on all the railroads throughout the country until the advent of the telephone.

Telegraph Development. The earliest installations of the telegraph made use of the simple Morse circuit; the later developments provided duplex and quadruplex operation which were quite generally used for message service, especially between terminal or relay points. It might be said that the development of the telegraph as a means of communication progressed in step with the development of the railroads themselves. The importance of rapid and accurate communication was greatly increased by the increase in mileage of the railroads the efficient management of which required prompt, accurate and complete information regarding many matters pertaining to operation and management. The telegraph is still used by some roads for dispatching their trains and handling the regular message business, although the telephone has rapidly replaced it for this class of service in many sections.

Telegraph as By-Product. Although on some railroads and some divisions of the railroads the telegraph has given way almost completely to the telephone for all classes of local service, yet it is probable that for many years to come the telegraph will still be used as a by-product of the wire plant for message service between the general office and division headquarters; also between the different relay points on the systems. This telegraph service will not be handled over direct Morse wires, but rather be a by-product obtained by compositing the telephone trunk circuits between these same points. This would mean that two pairs of telephone wires which are properly transposed can be phantomed and composited and thus furnish three telephone and four duplex telegraph circuits, all of which may be operated simultaneously without interference of one with the other. These composited circuits may be equipped with telegraph repeaters for through telegraph message business over the long circuits of, say, 300 miles or more.

Commercial Telegraph Service. For the benefit of the public, commercial telegraph offices are provided at the terminals and larger stations, and messages are handled by the railroad operators at other points.

Arrangements are in effect at many important points on some railroads for the uniformed messengers of the commercial telegraph companies to pass through the trains and collect telegrams from the passengers. Messages are delivered to passengers enroute by sending them in care of the conductor of the train (indicating by train number) on which the passenger is traveling. They are then delivered at the next point at which the train stops.

1. Pennsylvania Railroad System, Philadelphia, Pa.

Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925.

Telegraph Printers

The telegraph printer has been developed to the point where it is being used very largely between division headquarters or relay points or where there is a sufficient volume of traffic to warrant their installation, and these same composite circuits referred to above, can be used for duplex operation of these machines.

Reports. For the efficient handling of freight and passenger business on a large system, it is necessary for those in charge to have current reports on the supply and demand of cars and the movement of the different classes of freight and engines; also on shop conditions where the different classes of repairs are made. This necessitates the use of many different report forms, for years handled by the Morse operators. An intelligent study of this condition would make it possible to redesign many of these forms so that they might be used in printer operation.

Type of Printer. It is believed that the page printer using tape transmission is, in general, most satisfactory for railroad message work between the more important points. Several carbon copies of the messages or reports can be made when this is necessary and very little instruction is required to teach one to manipulate a printer if the employe is able to operate a typewriter accurately. When line interruptions occur, the perforator operator can continue to punch the transmitting tape, and as soon as the line is restored the tape can be run through the transmitter at maximum line speed with minimum of delay.

Maintenance. The maintenance of printers requires the services of a skilled mechanic, so that the more printers there are in service at a given point the less the cost of maintenance per unit, as one mechanician can take care of a number of printers.

Telegraph Replaced Largely by Telephone

The disadvantage in using the telephone in train dispatching in the early stages of its development was caused by the difficulty in signaling the desired party, as it was necessary to use code calls and this was very objectionable on heavy lines. There were many misgivings and doubts regarding the ability of the dispatcher and operators to handle train orders accurately by the telephone, and it was only after quite extensive use on certain limited installations that the telephone proved to be quite equal to the telegraph so far as accuracy and speed were concerned.

The more general use of the telephone for train dispatching was dependent upon the development and perfection of a selective calling device, which would enable the dispatcher to signal any one of the many stations connected to his telephone circuit. There were a number of types and makes of selectors in the early development, but the law of the survival of the fittest worked here as well as elsewhere and the selectors at present available for this service are both rugged and accurate with relatively little maintenance trouble. They are available for circuits having as many as seventy-five or more stations any of which can be called independently; but on a busy section of railroad they seldom exceed half this number. The approximate time required for the bell to start to ring after the dispatcher makes the call is four to six seconds.

Time Service. One important service which was formerly handled exclusively by telegraph and which is now quite generally transmitted over the telephone lines equipped with selectors is the time service from the U. S. Observatory. This transmission takes place twice a day, at noon and midnight in the Eastern time belt, and is an important service, as all the time pieces on the railroad used in connection with train operation for reasons which are obvious must be as nearly accurate as it is possible to have them.

Telephone

So far as the public is concerned, they are interested primarily in telephone service with the railroad company to obtain information regarding such matters as arrival and departure of trains, Pullman reservations, cost of transporation, arrival and departure of freight, freight rates, etc.

When it is realized that the railroads are the largest users of almost every commodity, it will be evident that there are many other classes of information in which the public are very much interested at times and in which the telephone system forms an important link.

Intercommunicating System. In some of the larger cities, the different departments of the railroad are quite widely separated on account of the quarters required and those available; but the intercommunicating telephone systems, which may be automatic, manual or semi-mechanical, make it possible to secure those best adapted for the business by the telephone service which is as prompt as if all the parties were in adjacent offices.

Private Intercommunication System. In some places where the calling rate for strictly intercommunicating service is unusually high between the different subscribers it has been found to be economical to purchase, maintain and operate a private system of the automatic type, but this means duplication of the outside plant, wiring and maintenance, and requires a second telephone where there is occasion to have service with the commercial companies. Only a careful study, considering all items involved, will give the true answer as to the economies of this.

The long distance or trunk-line circuits of the railroad company represent an appreciable investment which should be operated as efficiently as possible to secure the best returns. This means that a relatively small number of lines are given to each toll operator who is selected because of efficiency, and knowledge of the railroad organization and can be depended upon to handle the circuits to the best advantage.

Directory Listing. It is impracticable and undesirable to list in the public telephone directory all the different departments, much less all of the individuals, of a railroad organization, so that the burden of remembering each and all of the hundreds or thousands of individuals within reach of the telephones connected to such a switchboard becomes a problem of long and careful training.

The aim of the railroads, generally, is to simplify as much as possible the directory listings, so that by calling one telephone number, connections may be established with any department or individual in that vicinity.

PBX Consolidation. This is one argument in favor of the consolidation of the private branch exchanges of a railroad where there are several exchanges in a given vicinity. The cost of service through such a consolidated exchange is the deciding factor sometimes, as it might be necessary to lease a considerable mileage of cable circuits from the outlying points to the consolidated exchange; and if that rental and the rental of the additional facilities required at the consolidated board exceed the cost of the service through the individual exchanges, then the only remaining arguments are the twenty-four hour service and the greater convenience to the public from the simplified listing.

The advent of the automatic or machine-switching system it is believed will solve many of these problems, as the small automatic unit, called a satellite, can be used for the intercommunicating service at the points separated from the main exchange and connected with the railroad main *PBX* by automatic trunks. The calls to and from the city central offices then would be routed through the main *PBX*. The railroad operator would complete the incoming calls either by dialing the party, if on a satellite exchange, or by a cord and plug in the multiple if connected on the same switchboard. The outgoing calls would either be dialed direct by the different railroad subscribers or handled by the operator as desired by the railroad company.

PBX Traffic. During the busy hour it is not uncommon for an operator handling calls incoming from city to make 200 connections, and a considerably higher number of intercommunicating calls when made by number. The former class of calls probably will continue on a manual basis even after the central office and the private branch exchange are operating on a machine-switching basis. Through some of the larger private branch exchanges they handle as many as 18,000 to 20,000 or more calls per day.

Train Dispatcher's Equipment. There may be several dispatchers' circuits on a busy division, each dispatcher handling the movements over a given section with possibly a Chief Dispatcher's circuit operating over the entire length of the division and connecting to certain transfer points and with the dispatcher's office on one or more of the adjoining divisions. On these circuits equipped with selectors the dispatcher has control of the entire circuit; that is, the different way stations are signaled only by the dispatcher who is, in general, connected across the circuit continuously with his receiver, which may be of the head band type or a loud speaker.

For a long time the head-band receiver, used by the dispatcher, was the only type of reliable receiver available. It was very objectionable however, especially in warm weather, during lightning storms, or where the circuit was exposed to the effects of induction from power circuits. This trouble has been largely overcome by the development of the loud speaker which, at present, is very satisfactory for this service. The loud speaker can be so adjusted that, even though there are several of them in an office, a very satisfactory operation is obtained. This is convenient also for the supervisory forces in case of emergency, as they can get all details first-hand without disturbing the dispatcher.

Selector Message Circuits. Telephone circuits equipped with selectors also are used quite extensively for handling telegraph messages, especially between local division points.

To prevent errors in the transmission of words and numbers that might be misunderstood, a special code has been developed and is in very general use. The service is faster than the Morse and very little special training is required for such operation.

The installation of telephone selector equipment for train dispatching and message service generally has been objected to by those who are accustomed to handling this business by Morse, but it also has been quite general that these same objectors are the most enthusiastic proponents of the telephone system after they have become accustomed to this operation.

Block Circuits. Interlocking plants are located at regular intervals along the railroad, permitting the crossing over of trains from one track to another on a system having two or more tracks, and also allowing the trains to take a passing siding on single track operation. These points are known as interlocking stations.

Where interlocking stations are several miles apart, intermediate stations are often established for the purpose of shortening the block between the interlocking stations. They are known as block stations.

The attendant in charge of the interlocking or block stations may be a telegraph or telephone operator and must manipulate the levers controlling the signals or switches. He is now quite generally known as a "signalman."

A "block," as used in this paper, is the length of track between block or interlocking stations where the movement over the track is governed by fixed signals.

Telephone circuits between these block and interlocking stations are known as block circuits and are used for spacing trains and for transmitting intelligence regarding arrival and departure of trains in the different blocks. They are considered next in importance to the dispatcher's circuit so far as train operation is concerned.

Telephones in shelter boxes or booths are usually located at the different sidings and signal bridges and connected to the adjacent block or interlocking stations, or, in some cases, to the dispatcher's line.

These block circuits are often simplexed and the simplex carried through for a division telegraph circuit.

Work and Wreck Train Equipment. The work trains and wreck trains are quite generally equipped with portable telephones which may be connected to the adjacent block and interlocking stations or to the dispatcher's telephone circuit, to keep him advised of their whereabouts; also as to condition of track or equipment on which they may be working. Before the advent of the telephone for this service, it was necessary to establish a local telegraph office and an operator was required with the work-train or wreck-train crew to transmit the necessary information to and from the dispatcher.

First-hand information can now be obtained direct from the one in charge of the train crew in less time and more satisfactorily than was possible with the telegraph.

Siding and Signal Bridge Telephones. On some roads it is the practise to establish telephone service at each signal bridge and siding. This telephone is connected to the adjacent interlocking or block station. In some cases provision is made for conection to an adjacent private branch exchange in case of emergency, so that the calling party may be connected either directly to the signal man, to the dispatcher or other individual depending upon conditions. These telephones are usually installed in shelter boxes or booths to protect them and the user from the weather. Automatic switches are used to disconnect the telephone from the line when the telephone is not in use. These shelter boxes or booths usually are provided with regular switch locks to prevent the use of the telephone by unauthorized persons.

This general scheme of installing telephones along the railroad right-of-way, especially on a busy section, is considered more favorably than the use of portable telephones as they are available for all the different employes of the railroad system in that district, and less apt to develop trouble than the portable sets. They are also inspected more regularly by the maintainers.

Emergency Circuits. In some cases an extra circuit is provided in the shelter boxes or booths. This is termed an emergency circuit and is available for service with an emergency or portable telephone carried by the work- or wreck-train crews, so that it does not interfere with the operation of the regular signal bridge or way-station telephone circuit. The emergency circuit is associated with the adjacent block and interlocking stations and so arranged that it could be connected to the dispatcher or to a private branch exchange in the event of an emergency.

Portable Telephones. The renewing of ties and rail, together with other work on the track incident to track maintenance, requires that a track gang should be in constant communication with the train dispatcher, so that there will be as little delay to train movement as possible. The use of the portable telephone is essential in this operation and it also improves the efficiency of the track forces by a reduction in their lost time.

Loud Speakers at Terminals. In a busy terminal where there are crossovers, interlocking equipment, etc., it is desirable for each of the signalmen at different stations to know of all of the train movements arranged by the dispatcher in that district. This was handled by Morse for many years, but when the train and engine movements increased so much it became a great strain on the signalman. The head telephone with a long cord required to permit the signalman to handle the different switch levers, is impracticable so that more recently the loud speaking telephone has been used quite generally to solve this problem, and it is working very satisfactorily.

Observation Cars. Observation cars on certain limited trains are provided with desk telephones which are in turn connected to the railroad private branch exchanges thence to the city central offices when the trains are at the different terminals. This service, connected through to any point in the Bell System, is available for the passengers on the train up to the leaving time. The stenographer on these trains arranges for this service as desired.

Crew Calling. At some of the important division points the homes of the conductors, brakemen, engineers and firemen are quite widely separated from the division office. Due to different emergencies which may arise, the variation in the amount of traffic requiring different numbers of crews, sickness and other causes, it is quite a problem to make available the necessary men qualified to handle the different freight and passenger trains without delay. This requires either special messenger service or special telephone service. It has been found in some instances that special crew-calling telephone service, (normally used for one-way operation but in emergencies employed for two-way service), is the most efficient and economical. With this system the Crew Caller gives the Telephone Operator the list of members to be called indicating time and place to report for duty.

Public Telephones at Stations. For the convenience of the traveling public, and not directly associated with railroad operation, a relatively large number of telephones is required at many of the important terminals to enable the patrons to make local and long distance calls through the commercial telephone systems. This convenience is provided for by the attended and unattended telephone stations, the latter being the usual coin in the slot or pay station telephones.

Train Bulletins. On many roads a regular bulletin service is also in effect giving information of general interest to the traveling public on through limited trains. This includes stock market quotations on the principal issues, base ball scores, and any other items

of major interest. These bulletins are generally posted in the club or observation cars and are received at the principal points enroute.

Telautograph

The telautograph has been used quite generally for recording information regarding the make-up of trains, track assignment for trains also the time of arrival and departure of different trains in the terminals and other important division points. This is a service which is of vital importance to the baggage department and in handling mail as arrangements must be made to load baggage and mail on the trains the latest possible before train departure also for the necessary trucks to unload promptly incoming baggage and mail from the trains just arriving. This service is of a local nature. The circuits may have one or more transmitters and several receivers, all of which are operated simultaneously.

Radio

Passenger Trains. Radio on passenger trains has been an interesting theme for many of the Sunday newspaper writers for some time; and they have not overlooked many of its possibilities.

The developments that have taken place in the broadcasting and receiving equipment within a few years and the results obtained from some of the experimental installations indicate that if there were a real demand for such service on our trains it could probably be met now in a more satisfactory manner than at any time in the past. There are many factors that affect the results obtained on a train installation including: the curvature of the track, causing changes in position of the car antenna with respect to the transmitting station; varying sub-surface conditions which apparently cause fading or varying intensity of received signals or sounds; shielding effect of tunnels and bridges, causing a reduction in intensity or complete loss of reception; noise from axle generator lighting equipment; in addition to the atmospherics that affect the fixed station.

There are certain events that are of general interest which might be received over a radio loud speaker in a club or observation car without much adverse criticism; but that would not hold good with the ordinary broadcasting.

Freight Trains. There is a real need for a sturdy, reliable, simple set for two-way communication between the front and rear end of long freight trains, which is reasonable in cost, This should have some scheme for visual or preferably audible signaling. The rails have been suggested as a conductor for a carrier system. These have insulated joints at certain intervals which might affect the operation, and on account of the connections between the different tracks at the interlocking points, there might be some complications or objections to such use.

The importance of this will be appreciated when one considers that some trains are nearly a mile long, with a hundred or more cars, the engine crew at the head end, the conductor and flagman in the caboose at the other end and the brakemen out over the train. Something goes wrong and the conductor wants to communicate with the engineer. It is a dark, rainy or foggy night, and in a place where the track winds around the hills with no opportunity for lantern signals. There is nothing to do but stop the train and walk the length of it. This takes a long time.

Train Operation. It is believed that the radio can not yet be depended upon for issuing train orders, especially to moving trains, as accuracy is of prime importance, as well as continuity of service, and there must be a check on all orders issued by the dispatcher.

Emergency and Tug Boat Service. It has a real field, however, for emergency service between the different important points such as the general offices, division headquarters and certain important points on a system, when the wire lines fail because of storms, floods, fire, etc.; also for tug-boat operation in the harbors. The code signals are more reliable than the telephone for such service.

Small, efficient, portable transmitting and receiving sets which could be depended upon for distances up to two or three miles for service during floods and storm breaks would find favor with the railroad Superintendents of Telegraph.

Line Construction

Location. The telegraph and telephone line construction is invariably along the railroad right-of-way, which which means that, in general, it is not far from the running tracks and is subjected to the smoke and corrosive gases from the locomotives where steam operation is used.

Types of Line Construction. The different types of line construction used in various sections, dependent upon local conditions, include open wire, aerial cable and underground cable. The construction used in any particular section depends upon several things such as the number of circuits involved, the importance of the service, space available and hazards from electrical or mechanical interference. The appearance of the line, also, is an item in some sections. Each class of construction mentioned has certain merits as well as objections, for which reason the conditions in any given location have to be carefully considered before deciding upon just what should be used.

Preservation of Poles. The railroads have been active in the development and use of preservative treatment of pole timbers for years. Because of their use of forest products, amounting to about fifteen per cent of the total consumption in this country, they realize that this is a good and wise investment and in line with the policy of forest conservation.

Insulator Pins. If it were possible to obtain a satisfactory enameled pin which would preserve the metal pin from deterioration and also provide the necessary

strength and insulating qualities at a reasonable price, it might be an improvement over the present practise.

Wire. Galvanized wire is used very little along a busy railroad on account of its short life before corrosion takes place. Practically all wire now placed is hard drawn bare copper No. 9 A.w.g., except that No. 8 B.w.g. is used for some important long distance trunk circuits.

Insulation. On a busy section of railroad the locomotive smoke is responsible for insulators soon becoming coated with a black deposit which covers not only their outer surface but underneath the petticoats as well, and is responsible for lowered insulation under unfavorable weather conditions. This causes leakage of current from the wires to ground and between wires, which affects both the telegraph and telephone service, probably the telegraph more than the telephone. This has been the subject of quite exhaustive studies to determine the best type of construction.

It has been found uneconomical to attempt to clean the insulators after they have once become coated; so the remedy for this condition is to replace with new glass, unless some means is developed for preventing this accumulation or for economically and efficiently cleaning them in place.

Importance of Continuous Service. It is believed that the importance of continuous and efficient communication service in railroad opertion is greater than with the regular commercial telegraph or telephone service. It is under the most unfavorable weather conditions that irregularities are apt to occur in train operation and that, too, is the time when open wire lines are most likely to fail, and when they are most needed.

Alternate Routes. Alternate routes for circuits between some of the more important places are usually available over the Railroad Companies' lines, and, in the event of line prostration over a normal route, it is many times possible to reroute some of the circuits to provide for the emergency service while repairs are underway.

Cable Construction. Where cable circuits are in service, there is generally less likelihood of line failure due to storms; but they might fail from other causes, such as electrolytic action, if underground, or from bullet holes or crystallization if in aerial construction. In either case duplicate cables provide certain insurance against complete failure, but with adequate testing facilities and a force of cable splicers available, together with proper maintenance of the cable plant, there is little likelihood of these causes occasioning the loss of all service.

Wire Patching Facilities. All wires on the pole line look alike to the layman, but from a railroad operating point of view, some wires are vastly more important than others. The dispatcher's line is considered of the greatest importance in train operation and for this reason it is always restored first in the event of line prostration. If trouble develops on it while other circircuits are intact, the circuit which can be spared with least inconvenience to the service is used to patch out the dispatcher's circuit in the defective section. This means that the patching facilities, which include test panels in which all wires terminate and the necessary patching cords and plugs, must be available for this purpose at certain points on the Division. However, it is undesirable to have these located too close together, as they introduce certain transmission losses on the longer circuits due to the necessity of using cable and protectors to connect between the line and the test panel, which usually is located in an interlocking or block station. Thus the additional protectors are added places for trouble to occur.

Emergency Service. With the open wire construction it is possible to make connections for local emergency service by means of the pole used for this purpose, with portable telephones, but where aerial or underground cable only are used, these emergency connections can be made only where cable conductors are brought out to terminals, as at signal bridge or siding telephones or special terminals provided for that purpose.

Use of Commercial Lines. It is sometimes possible to establish emergency service between the different important points by connection over the commercial telegraph or telephone companies' lines, routed either as direct circuits between the points involved or by circuitous routes to avoid the section in trouble. For the purpose of quickly establishing such services, it is the usual practise to have available certain tie lines between the railroad companies' important terminal or relay offices and the commercial offices of the telegraph or telephone companies.

Operating Conditions

Variation in Telephone Traffic. There are quite wide variations in the traffic over the railroad companies' communication system, dependent upon the seasons. The increased travel during the holidays and vacation periods is also responsible for wide fluctuations in this communication traffic. The presence of any emergencies or conditions which are likely to cause delays in the train schedules are often reflected in the increased calls made from the public to the Information Bureau inquiring as to the probable arrival or departure of the different trains, the cause and results of accidents, etc. In the event that these emergencies develop at a time when the telephone operating force is greatly reduced, there is apt to be complaint as to the inadequacy of the service unless extra operators are summoned immediately, as is usually the case. It is doubtful if the machine switching service will remedy this particular condition, as it is quite probable that all incoming calls from the city central office will be handled by the manual operators as at present, but intercommunicating calls within the system itself could well be handled on a mechanical basis so that the increased

load on the operators would not be so great as with the manual system.

Engineering Problems. The different problems met in the planning, operation and maintenance of a communication system for a large railroad are practically the same as with the large commercial telegraph and telephone companies, except that there are a few added special requirements. However, this phase of a railroad system is seldom given any consideration by one unfamiliar with the magnitude or importance of the railroad telegraph and telephone plant.

Interest in Legislation. When it is considered that some of the larger railroad systems operate in a number of States, it will be seen that the railroads are vitally interested in such matters as State regulations governing electrical construction, inductive coordination, etc., and in the revision of the National Electrical Safety Code which doubtless will have a far reaching influence on the State regulations now in effect, or which may be revised or formulated later.

Magnitude of Some Systems. The communication plant of one of the larger railroads includes, in round numbers, over 10,250 miles of pole line; 530 miles of underground duct; 125,000 miles of wire; 2420 telegraph and telephone message offices; the average number of messages per month, not including train orders, through 86 relay and terminal offices is over 3,716,000; more than 11,700 telephones, privately owned, are used for dispatching trains, message service and private line operation; over 180 leased telephone exchanges, ranging from simple one position boards to a 23 position board at the General Office, are employed with over 18,800 leased telephones. This is called a private communication plant.

Ideal System. The ideal communication system would be such that, from any point on a railroad, any information wanted from any other point on that system could be obtained accurately and without delay. This would require more plant than could reasonably be expected and of such a quality that only the highest grade of construction could be used; the lines would have to be equipped with loading coils and telephone and telegraph repeaters, and the terminal equipment would have to be such that minimum losses would obtain. Some of the railroads have already gone a long way toward realizing this ideal.

REPORT FROM RUSSIAN INFORMATION BUREAU, MOSCOW

WASHINGTON, D. C., APRIL 7—By October 1, the Soviet Government will have spent the equivalent of $70,000,000 in the establishment of seven regional power stations and the rehabilitation of existing stations. The announcement was received in a special issue of the *Gazette* of Trade and Industry, the organ of the Supreme Council of National Economy, dated March 7.

Russia has been conspicuously a backward nation in the development of electrical power. The Tsarist Government made no effort to exploit the immense resources of the country for electrical development. In 1917 there were 561 stations furnishing power for general domestic and industrial use and their total capacity was only 394,000 kilowatts. Plants not engaged in public service had a total capacity of about a million kilowatts. Only one station in all Russia was capable of furnishing 20,000 kilowatts. There was a sharp deterioration during the civil war period.

In 1920 the Chief Electrical Board of the Supreme Economic Council drew up a comprehensive plan for electrical development, but owing to lack of working capital little progress was made up to last year.

The first part of the program called for the restoration of existing plants to full capacity of about 1,500,000 kilowatts. This, it is announced, has already been accomplished. The second part of the program called for the erection of thirty new regional power stations with the capacity of an additional 1,500,000 kilowatts. Seven of these stations will be completed this year, furnishing by October about half their full capacity of 200,000 kilowatts. Four are already in partial operation. These plants are enterprises of the Federal Government, and in addition local authorities in five cities are erecting plants with an aggregate capacity of 30,000 kilowatts.

Of the seven regional stations, two will be in the Leningrad region, two in the Moscow region, one near Nizhni-Novgorod, one in the Don coal district and one in the Urals.

The regional stations will materially lower the price of electric current for the districts they serve. The Volkhov plant, near Leningrad, here water power is used, can produce power at a cost of 2 copecks (1 cent) per kilowatt hour, and the Shterov plant in the Don, running with small anthracite, can produce for 2.5 copecks per kilowatt hour, including provision for sinking fund. The stations near Moscow will use peat and coal waste as fuel.

Plans drawn up by the Government experts for the eventual complete electrification of Russia are based on an annual consumption of 50 kilowatt hours per capita. They will involve a total expenditure of fifteen billion rubles (about $7,700,000,000) and a total power capacity of 15,000,000 kilowatts. The thirty stations to be completed during the new few years mark the first phase of this ambitious program. It is estimated that the full program will cover at least twenty-five years of construction.

At the All-Russian Hydrological Conference held last year it was estimated that Russia's water power resources were equivalent to seventy million horse power. During his lifetime Lenin repeatedly urged that Russia's economic salvation was bound up in the transformation of its "white coal" into electrical power. The improved financial position of the Soviet Republic has made it possible to take the first steps towards realizing what was called "Lenin's dream."

Load Building Possibilities of Industrial Heating

BY C. L. IPSEN[1]

Associate, A. I. E. E.

***Synopsis.**—The author gives a brief survey of the more recent achievements in industrial electric heating, and shows the increasing tendency of industries to adopt electric heating, particularly for high grade products. Specific installation for such processes as steel treating, copper and brass annealing, vitreous enamelling, glass annealing, baking japans, cores, bread, etc., on a large scale, are described and illustrated.*

It is shown that the quality of product has been improved by the use of electric heating with little if any increase in cost, and in many cases, at a lower "over all" cost.

The desirability of heating load for the central station is emphasized, due to its high power factor and load factor.

* * * * *

THE success attained during the past few years in the application of electric heat to manufacturing processes, indicates that the electric heating load will have a far-reaching affect on the future development and growth of central stations.

A general survey of some of the more important achievements in the industrial heating field will be attempted in the hope that such a survey will assist the various central stations of the country to analyze the load building possibilities of industrial heating in their respective territories.

The use of heat in the preparation of raw materials, including the use of arc furnaces for steel melting and electro-chemical processes, will not be discussed in this paper. Attention will be directed rather to the heat required in manufacturing operations subsequent to the preparation of raw materials.

An appreciation of the extent to which heat enters into such manufacturing operations can probably best be gained by considering the various steps in the manufacture of some well known product. A familiar example, and one of which the manufacture probably best illustrates the extent to which electric heat has superseded other heat sources, is the electric motor. Heat must be supplied for annealing and enameling the punchings, annealing frame castings, and copper, for enameling and varnishing the wire, for japanning end shields, heating coil moulds, heating impregnating tanks and baking ovens, soldering, preheating rotors, melting aluminum used for rotor bars, and for heat-treating the dies and tools used in this line of manufacture. Electric heat is now being successfully applied to most of these processes.

An analysis of the heat and power required in the manufacturing of most products reveals the fact that the energy required for heating greatly exceeds that required for power. Whether the electric heating load will ever equal the power load, as has often been prophesied, will thus depend upon the extent to which electric heat will be able to supersede other heat sources. At present, only tendencies in this direction can be definitely stated. These tendencies can probably best be brought out by considering the achievements of electric heating in individual applications. Accordingly, a few installations in each of the following fields, where electric heat is now successfully competing with other heat sources, will be discussed:—viz.

I. Steel Treating
II. Copper and Brass Annealing
III. Vitreous Enameling
IV. Glass Annealing
V. Baking Ovens
VI. Impregnating Tanks

Steel Treating. Heat is used in steel treating chiefly for annealing, hardening, drawing and carburizing.

FIG. 1—ELECTRIC SHEET-STEEL-ANNEALING FURNACE

Annealing has for its main object, the softening of steel to increase machinability or ductility, the relieving of casting strain, or, in the case of electrical sheets, the reduction of eddy current and hysteresis losses.

Fig. 1 shows an electric-annealing furnace of the elevator type, for annealing sheet steel. The sheet steel is stacked directly on top of the furnace car without the use of the annealing boxes familiar in fuel-fired practise, and the car is charged into the furnace by a hydraulic elevator. This type of furnace is used in preference to the more common car bottom furnace with doors, since the air can be more effectively excluded and the furnace atmosphere controlled.

Since the heat in the fuel-fired furnace must be supplied by combustion within the furnace chamber, prod-

1. Industrial Heating Dept., General Electric Co., Schenectady, N. Y.

Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925.

ucts of combustion are present which have a strongly oxidizing effect on the punchings or other material being heated. Heavy steel or iron boxes which, in many cases, exceed the weight of the punchings themselves, are required to protect the punchings from this oxidizing atmosphere. Thus, the fuel-fired furnace labors under the disadvantage of heating practically twice the material heated in the electric furnace for a given output of punchings and, at the same time, is charged with a high annealing box depreciation. These two factors have made it possible to materially reduce annealing costs with the electric furnace.

This advantage, coupled with others of lower maintenance costs, more uniform product and better working conditions, indicate that the field for electric annealing of sheet steel is one capable of great future expansion. Fourteen electric furnaces of this type, having a total connected load of 2200 kw., are now being operated by one concern.

The widespread adoption during the past few years of electric-melting furnaces by steel foundries, is now being followed by the general adoption of electric furnaces for annealing. Since annealing can be carried on without attendance, it is usually done at night to secure the advantage of low off-peak rates. The advantages secured are a better and more uniform product, less scaling and better working conditions.

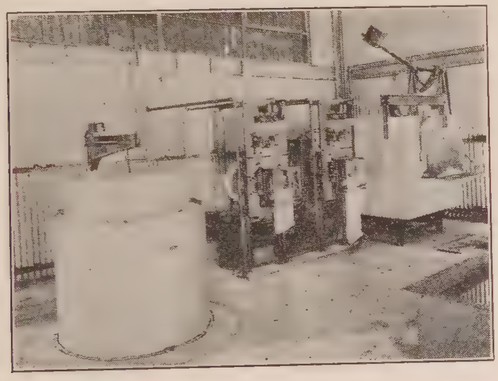


Fig. 2—Electric Tool-Hardening Furnaces

Steel is hardened by heating above its critical or transformation point and cooling quickly by immersion in some quenching medium, such as water or oil. This treatment greatly increases the hardness and tensile strength at the same time decreasing its ductility or toughness. The proper combination of hardness, tensile strength and toughness is secured by subsequent heating, known as drawing. Hardening and drawing are applied to tools and dies to give hardness and strength to the cutting edge, and to automobile parts, etc., to give maximum strength and toughness.

A typical tool-hardening room equipped with electric furnaces is shown in Fig. 2. Tool-room furnaces are usually of the box or pit type and require an energy input of from five to forty kw., depending on their size. These small electric furnaces have been found particularly useful in demonstrating to manufacturers the superiority of electric heating, and have in factories where they are used thus formed the basis for the more extensive use of industrial heating, for other processes.

Uniform heating of steel to the proper temperature throughout its mass is essential in order to secure maximum properties of hardness and strength. Even a slight deviation from these conditions will greatly reduce such properties, or may even cause the breakage of a tool or die in quenching. This clearly marks the hardening of dies and tools as the field of the electric furnace, with its accurate temperature control and uniformity of heating.

It is interesting to note that these advantages can be secured at average commercial rates for electricity without additional operating cost. To definitely establish this point accurate tests have been conducted in several plants. It might be well to add, however, that undue prominence is often attached to the cost of fuel or electricity for heating operations. A careful cost analysis, made of several steel parts, showed that the cost of electricity used for heat treating averaged only one-half of one per cent of the factory cost of the parts, while improvements in these parts equal to many per cent could, in most cases, be definitely credited to the electric furnaces.

The advent of the automobile, with its requirements for lightness and great strength, has given pronounced impetus to the heat treatment of steel. Some parts, such as ball bearings, are heated as many as six times during their manufacture. The same care and accuracy in heating are required as for tools and dies and, accordingly, many of the automobile manufacturers are turning to the electric furnace as a means of securing maximum results.

The operation of electric furnaces for this work over a period of three or four years has clearly demonstrated that not only can maximum results be obtained through their use but that these results can be secured at a lower "over-all" cost. In most cases the cost of electricity exceeds the cost of oil but this higher cost is more than offset by lower rejections, greater uniformity of hardness making possible the speeding up of subsequent machining operations, less cleaning, less labor, and more favorable working conditions which, in turn, results in lower labor turnover.

Continuous furnaces, in which the parts are pushed or carried through the furnace and quenched automatically, are used extensively for this work.

Fig. 3 shows a rotary-hearth furnace in common use for heating gears and small parts. A furnace of this type was installed by one concern four years ago. This concern now has seven such furnaces in operation with a total connected load of 1200 kw. Space permitting, numerous other examples could be given in the aggregate showing a very definite trend toward the complete

electrification of this important field with its enormous load-building possibilities.

Carburization of steel consists in increasing the carbon content of the surface of a soft steel part by heating it to high temperature in the presence of carbon. The steel parts are packed in a suitable container with carbonaceous material, heated in a furnace to the proper temperature and held at this temperature for a period

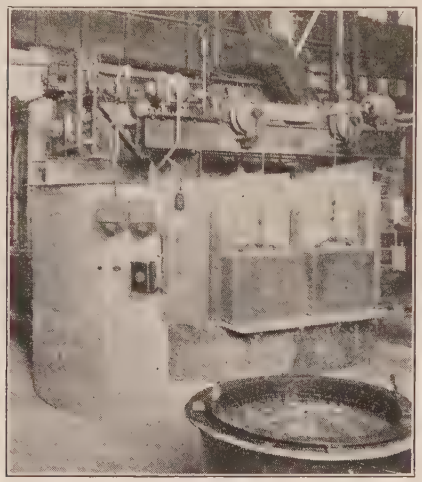


Fig. 3—Electric Rotary-Hearth Furnace

of several hours. Numerous installations of electric furnaces have proved them ideal for carburizing and on the cost basis alone able to successfully compete with fuel-fired furnaces. This is due to the high efficiency of the electric furnace during the long "holding" period.

Longer life of carburizing boxes, less labor and more uniform results are advantages gained by the electric

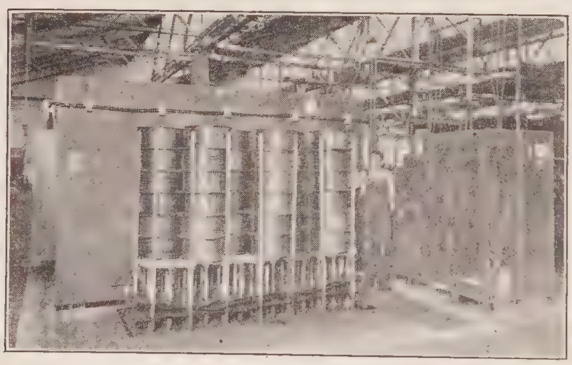


Fig. 4—Electric Copper-Annealing Furnace

carburizing furnace which promise to give great impetus to its future use.

Copper and Brass Annealing. The working of copper and brass increases its hardness and reduces its ductility. With continued working, the hardness of the metal reaches a point where any further reduction would cause it to break. It is then necessary to restore its softness and ductility by heating or annealing. In the manufacture of light gage sheet or wire it may be necessary to anneal several times. A final accurate annealing of some finished products is of vital importance. A good example is the copper used for electric motors and generators where great ductility is required to prevent crystallization and breakage due to vibration.

An electric furnace for bright annealing copper wire is shown in Fig. 4. In charging the furnace the platform, with its load of copper, is lowered by a hydraulic cylinder into a pit filled with water. The furnace is mounted on wheels and, by means of another hydraulic cylinder, is pushed into a position directly over the submerged charge of copper. Raising the platform to its original position then places the charge inside the furnace chamber. Two platforms are provided in order that one may be loaded or unloaded while the other is being heated.

Heating units are mounted on the walls of the furnace, radiating their heat directly to the charge.

Fig. 5—Electric Vitreous Enameling Furnace

Bright annealing is secured by keeping the furnace chamber filled with steam and thus precluding the air. Accurate temperature control and uniform heat distribution produce uniform results which can be absolutely duplicated in every heat.

In the fuel-fired furnace, steel muffles are required to exclude the products of combusion from the working chamber.

The chief advantages gained by electric furnaces of this type are lower costs and better and more uniform product. One company has five of these furnaces in operation with a total connected load of 900 kw.

For brass annealing, a large tunnel type of furnace is usually employed. One such furnace, with a connected load of 500 kw., has been in continuous operation for three years. The cost of electricity slightly exceeds the cost of oil but advantages, such as less scaling, greater uniformity of hardness, and lower rejections, have made the "over all" cost in the electric furnace lower. Several such furnaces are now in operation.

Vitreous Enameling

In applying the vitreous enameled coating, familiar in lighting reflectors, kitchen ware, and sanitary ware, it is necessary to heat the metal to a high tempertuare to fuse the coating and render it adherent to the metal. The coating, consisting essentially of pulverized glass, is applied to the metal either as a thin paste or liquid by dipping, or, as a powder, by dusting it on the hot metal. The former, or wet process, is used chiefly on sheet metal parts such as kitchen ware, and the latter for cast iron parts such as sanitary ware.

Fig. 5 is a typical installation of the furnace used for enameling sheet metal. The chief requirements of the enameling furnace are: 1. High rate of production, since the labor of charging the furnace constitutes a large part of the enameling expense. 2. Pure furnace atmosphere to prevent contamination of the enamel. 3. Uniform heating to the correct temperature to maintain a high quality product. 4. Low maintenance cost. 5. A minimum of interruptions in production.

In order to meet the requirement of a pure atmosphere, it is necessary to either fire the fuel-fired furnace intermittently while the furnace is empty, thus reducing production, or to interpose a muffle between the combustion chamber and the working chamber. This also retards production and gives rise to frequency interruptions and high maintenance cost.

On the other hand, the electric furnace ideally fulfills all these requirements. At average rates for electricity, it suffers the disadvantage of a somewhat higher cost for heat. However, the large number of furnaces in operation have demonstrated conclusively, that in most cases other advantages of the electric furnace readily outweigh this higher heat cost and give a product of better quality at a lower "over-all" cost. One enameling company has, over a period of four years, increased its electric furnace installations to sixteen with a total connected load of 3500 kw.

Glass Annealing

Glass, as it comes from the moulds in which it is formed, is at a high temperature. If permitted to cool quickly in air, strains would be set up in it that would cause easy breakage. The formation of these strains can be prevented by cooling the glass slowly in a furnace or lehr. This lehr is usually of the continuous conveyer type, in which the temperature is graduated and the speed of the conveyer so set as to cool the glass to room temperature at the proper rate. There are certain critical temperatures in the cooling curve where great accuracy of temperature control is required to prevent the formation of strains.

Fig. 6 shows a typical electrically-heated glass lehr. It is heated by resistors mounted beneath the conveyer on the side walls and in the roof. These resistors are divided into five independent zones, each of which is arranged for automatic temperature control. The location of heating units gives a uniform temperature throughout the cross section of the lehr and the several automatically controlled zones make it possible to accurately govern the cooling of the glass along any desired curve.

This accuracy of control has made it possible to produce a glass of much greater strength, particularly noticeable in the reduction in breakage of electrically annealed glass in bottling machines. The cost of electricity for heating the lehr is, in most cases, higher than the cost of oil, but, as in many other instances referred to earlier in the paper, the cost of heat for annealing represents such a small portion of the cost of the finished product that even a slight improvement in quality will offset the additional cost. One company has installed eight lehrs during the past three years, with a total connected load of 1800 kw.

Fig. 6—Electric Glass Lehr

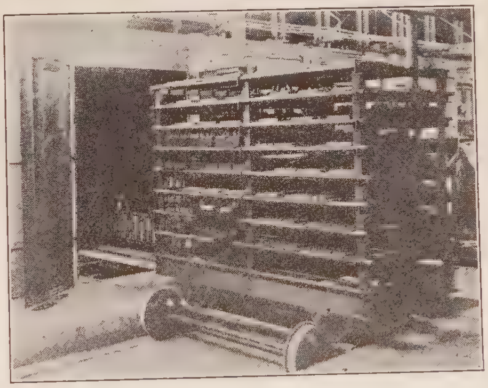


Fig. 7—Electric Core Oven

Baking Ovens

Baking ovens cover such a broad field that space will permit of only brief reference to a few of the more important applications, such as japanning, core baking, and bread baking.

The development of low temperature heaters for baking ovens preceded by several years the development

of suitable high temperature heaters for steel treating and other high temperature applications previously discussed. Accordingly, the low temperature applications have been more fully developed and still represent the greater part of the industrial heating load, exclusive of arc furnaces.

The extensive use of japanned metal for automobile parts, furniture, typewriters, cash registers, etc., make the field of the electric japanning oven from the standpoint of load building one of great importance. There are numerous installations throughout the country

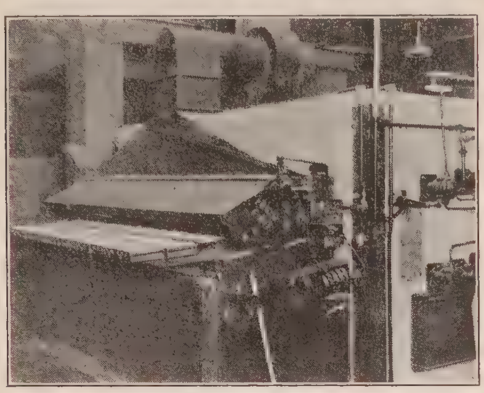


Fig. 8—Electric Bread-Baking Oven

ranging from small-box type ovens to great batteries of conveyor ovens. One company has a connected load of 12,000 kw. for japanning, built gradually up to this point over a period of ten years.

Because of the superior quality of electrically baked cores, electricity is becoming more generally used for core baking. Fig. 7 shows one of a battery of eighteen ovens used by one company. Another installation of 1000 kw. in core ovens is now in process of erection.

Bread baking by electricity has, for a long time, been successfully practised in homes, hotels and small bakeries. However, it is only recently, that the use of electricity has been considered for large bakeries. Fig. 8 shows a 450-kw. oven recently placed in successful operation. This oven is 9 ft. wide and 80 ft. long, and has an output of 4000 pounds of bread per hour. Accurate temperature control of the oven is secured by a large number of automatically controlled heating zones.

One 800-kw. oven and several smaller ovens are being used by one company for baking breakfast food. The cost of electric heat required for baking usually represents such a small part of the total cost of the product that even a slight improvement in quality will readily compensate for the additional cost of electricity for baking.

Impregnating Tanks

An interesting installation of electrically-heated vacuum impregnating tanks is shown in Fig. 9. Because of the fluctuations in steam pressure and the difficulty of securing high enough temperatures for all purposes, electric heating units were applied to these tanks. Contrary to expectations, the cost of heating electrically exceeded by only a few per cent the cost of heating with steam. Increased production as well as improved quality, made possible by uniform temperature distribution and automatic temperature control, actually reduced the cost per unit of product.

In addition to the large capacity installations discussed under these various headings, there are numerous other applications such as melting pots, soldering irons, glue pots, local heating units, etc., which, in the aggregate, represent a large load. These devices possess the advantage of low first cost and low operating cost and thus find a ready market.

The many advantages of electric heat over other heat sources thus established in numerous individual installations through a broad field of applications, indicate that the coming years will witness a great expansion of this central station load. It should not be overlooked that it represents a particularly attractive load from the standpoint of the central stations, for it is all at unity power and high load factor. Most of the furnaces

Fig. 9—Electric Impregnating Tanks

operate twenty-four hours a day but many can operate to advantage only during off-peak periods.

The rate of expansion of the heating load will depend, to a large extent, on the amount of effort spent in educating manufacturers to the advantages of electric heat. Effort was required to establish the electric light and electric motor as accepted standards in their respective fields; it now appears that similar effort on the part of electrical manufacturers and central stations will ultimately establish electricity as the accepted standard for industrial heating.

RADIO IN CHILE

Radio is very popular in Chile, it being estimated that 25,000 sets are in use at present, most of them being of the crystal type. Although sales are active, and it seems likely that the market will develop materially in the future, it is believed that the greatest future market will be for radio parts rather than complete sets.

Purchased Power as Applied to Plate Glass Manufacture

BY A. L. HARRINGTON[1]
Associate, A. I. E. E.

Synopsis:—*The paper gives some general statistics on plate-glass manufacture, and estimates that the present total electrical requirements of the industry in the United States, are about 350,000,000 kw-hr. per annum.*

About 60 per cent of this energy is purchased and is considered a very desirable load from the central station point of view, as the plants generally run almost continuously and shut down only a short time on Sundays, giving a very desirable load factor.

The paper briefly describes the manufacturing processes, and shows the different operations requiring the application of power. Specifically, it describes the 110-kv. station built for the Crystal City plant. This is designed along very simple lines to take the place of an isolated plant.

General Statistics, Plate Glass Manufacture

A SEARCH of the TRANSACTIONS of the Institute for quite a number of years back fails to show any papers presented on this subject, or, in fact, the application of electric power in any way to the manufacture of plate glass. In consequence of this, it might be well to present to the Society the general magnitude of the business as it affects central stations; then go into details.

It appears that the first attempt at plate glass making in the United States dates back to about 1850. Nothing came of this and, in fact, various companies were formed and failed. Until 1883 no company seemed to be successful commercially. From that time on, plants have been built in small numbers until, at the present time, there are about sixteen separate factories operating.

In 1884 approximately one and one-half million square feet of glass were produced; now the American production is about one hundred million feet while approximately twenty-five million feet are imported.

Raw Materials Affecting Plant Location

Large amounts of very high grade silica sand, natural gas or coal and considerable quantities of water are required in the business, and most of the plants are located in a rough rectangle with Pittsburgh, Buffalo, Chicago and St. Louis as the four corners. In nearly all of this territory the supply of natural gas was plentiful and as it was particularly desirable as compared with producer gas which is now generally used, and as the melting end of the manufacture required about one-half of the total fuel used, a cheap and plentiful supply of natural gas largely dictated the location of the plant.

Previous Sources of Power

In the early plants most of the work was done by hand and most of the product was of relatively small dimensions. Gradually, however, individual high-speed engines were used for the grinding and polishing processes, to be later supplanted by Corliss engines, driving line shafts, from which principal units were driven through friction clutches. This later development required that the machines be driven at constant speed and about this time a development in the machinery itself made that feature possible. Line-shaft driving attained its maximum when 5000-h. p. engines were put in use.

Natural- and producer-gas engines were the next development, driving generators, many of which were 25-cycle, the principal units of the load being operated by means of belted motors. Overhead cranes and industrial locomotives were usually operated by 250 volts d-c., obtained by smaller gas engines or motor-generator sets.

Total Kilowatt-Hour Required

The present total requirements of the industry probably call for something like 350,000,000 kw-hr. per annum in the United States and an increasing percentage of this is being transferred to central station systems. At the present time, about 50 per cent of this is used in completely electrified plants and at least 60 per cent of this energy is purchased. In several of the larger plants, new power houses were built fifteen to twenty years ago and the normal depreciation of these plants has brought their life to an end within the last few years. So the question of changing over to central-station power has recently become a very important one.

Load Factors

Plants usually run continuously, shutting down only from eight to sixteen hours on Sundays during which time maybe 15 or 20 per cent of average power is required for operating machine shops, pump houses, cranes and locomotives. The annual shutdown, due to the necessity of making certain repairs about the furnaces, may decrease the demand on the power system to 10 or 15 per cent for two or three weeks, but in the event that a stock of semi-finished glass is available, the machinery part of the plant may be continued in operation, which makes a very desirable load from the central station man's view point.

---

1. Pittsburgh Plate Glass Company, Pittsburgh, Pa.

Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925.

Central Station Power Applied to Particular Plant

It so happens that at the present time one of the larger plants of the country, located within transmission distance of St. Louis,—namely, the Crystal City, Mo. plant of the Pittsburgh Plate Glass Company,—is being changed over to central station power and, as certain features of this changeover may be of interest to electrical engineers, this paper is prepared to make such information available.

In order to give a clearer understanding of the detailed application of power, we might describe briefly the process of plate glass manufacturing.

Detail of Manufacturing Process

The raw materials are chiefly a high grade silica sand, soda ash, limestone, together with a very small amount of sodium sulphate charcoal and arsenious oxide. The proper mixture of this raw material in a perfectly dry state is accomplished in a manner similar to that used with concrete. It is placed in fire-clay pots, which are, in turn, placed in the equivalent of an open-hearth furnace. The temperature is gradually raised until melting is complete. This is followed by a few hours of refining, after which the furnace is allowed to cool down so that the glass attains the consistency of "cold molasses." The pot is then removed from the furnace by an overhead crane and dumped on a water-cooled cast-iron table, somewhat larger than the largest plate desired to make. This is done by means of a special crane giving a motion to the pot very similar to a mason placing a trowelful of mortar on the brick.

A water-cooled cast-iron roller is then rolled over the hot glass, the thickness of the finished sheet being determined by flat strips of metal put under the ends of the roller. After the plate is cooled sufficiently to be capable of being pushed by its cold edge, it is forced into an annealing oven and is, by various mechanical methods, moved through a series of annealing ovens so that eventually it comes out at atmospheric temperature.

The "rough glass," approximately ½ in. thick, is roughly examined and cut in such a way as to remove defects, and stocked.

The next part of the cycle consists of grinding and polishing. The first step is to secure a sheet of rough glass to the approximately true top of a circular table which, when placed in the grinding or polishing machine, is in effect the same as a table of a boring mill. This attaching of the glass to the table is done by plaster of Paris so that but little time is consumed and yet the attachment is not so good but that it can later be quite easily separated.

Referring to illustration, Fig. 1, which is a vertical cross-section taken through the grinding or polishing machine, it will be seen that the table which is provided with four wheels to operate on a system of tracks around the works, is supported by and revolves with the circular casting at the top of the large shaft, which casting at all times remains secured to the shaft. It is evident that relative vertical motion of some part of the machine is necessary to place the table on the "spider" and this is usually accomplished in either one of two ways:

First, the tracks over the machine may be lowered by hydraulic jacks or equivalent, so that the table comes down on top of and rests on the spider, the rails going downward a sufficient amount to clear the wheel flanges: Second, the rails may be kept permanently in position and the shaft, together with the spider on the top, may be raised by a hydraulic jack until it lifts the table from the rails.

In the plant in question the last method is the one in use and the hydraulic jack at the bottom of the shaft,

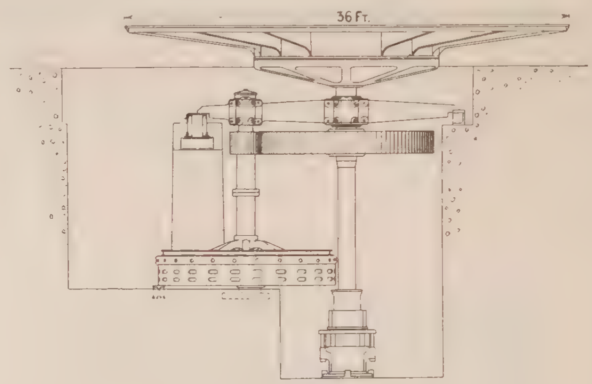


Fig. 1—General Cross-Section, Grinding and Polishing Machine

together with a safety lock or wedge, is introduced after the operation is completed, is shown at the bottom of the pit.

Grinding is accomplished with sand and water applied between the glass and iron blocks. These blocks are usually secured to disks, two or more of which are in contact with the top of the glass, with axes parallel but not in line with the main shaft. It is evident that rotation of the table produces a torque on these "runners," which revolve freely in their bearings, and pick up a speed intermediate to the table.

After coarse grades of sand have been applied, finer grades are usually followed by several grades of emery until the glass is as smooth as it is possible to make it. The table is then stopped, removed from the spider, transferred to another machine which is similar so far as the driving mechanism is concerned, but having in place of the cast iron blocks, pieces of felt saturated with iron oxide—"rouge"—and the glass is thus brought to a polish by the operation of the machine.

After one side of the glass is ground and polished, it is necessary to turn the plates over, bed them in plaster again, and repeat the cycle, after which the glass is removed from the table, washed with acid to remove the plaster, and, when dry, cut up into desired sizes and placed in stock.

In considering the application of electric power to the complete process of manufacture, we might first give consideration to the handling of the raw material. This is a proposition for handling raw material in which the usual methods are used and the only thing to be considered in applying a motor relates to the fact that the principal component, dry sand, is very highly abrasive. The other components, being alkaline, will attack certain parts of the equipment, particularly in the presence of moisture, and as a final item to look out for it is necessary to use every precaution to keep stray iron out of the batch material, which calls more or less for the use of magnetic separators,—usually pulleys.

The manufacture of the clay pots and other large amounts of fire-clay products is more or less similar to brick manufacture except that the clays are in a greater state of purity and must be kept so, and must be far more thoroughly mixed. The machinery consists of extra long pug mills in which the clay is mixed with water to the proper consistency, with rock crushers to crush up the raw clay, as well as fragments of previously burned clay, and chaser mills which grind the mixture of the different clays into powder.

Induction motors seem to be the proper driving medium and gear boxes, or similar devices taking up as little room as possible and closed against the entrance of dust, should be the connecting medium. As most of these machines either start up under load regularly or accidentally, they should be provided with slip-ring or double-wound rotor motors, 40- or 50-h. p. motors being about the limit as to size.

The entire melting or manufacture of the rough glass does not represent any features of interest to the electrical man, except in one or two small details. One of these is the "teeming crane" that pours the pots on the casting table. This teeming crane must move horizontally not more than twenty feet in two seconds, starting and stopping within this distance; and the motion must be combined with the pouring motion which occupies even less distance in this period. This power problem is usually met by applying a direct-current crane, or better still, mill motors and control that has practically no current or time limits.

The other item of interest is the considerable number of electric pyrometers required to follow the temperature of the glass throughout the various parts of the cycle.

The grinding and polishing part of the manufacturing process is the largest and by far the most important application of power as these machines consume upwards of 85 per cent of the entire power requirements. They also require the largest motors and are usually the only drives outside the ordinary daily applications.

Consideration of Main Drive

In the plant under consideration, 36-ft. tables are in use, a well recognized maximum general size at many of the larger plants; and this size table requires upwards of 700 h. p. for the polishers, the speed of rotation being somewhere from 10 to 15 rev. per min., and the grinders require upwards of 500 h. p. at approximately double these speeds. We, therefore, have the problem of applying electric power to a vertical shaft running at very low speeds, and of course the first scheme would be a direct motor application. There are no examples of this kind of drive in use but it has commercial possibility.

The next solution is using a higher speed motor with a single gear reduction; if the machine in general is of the type in which the rails are lowered to permit the revolution of the table, then the high speed shaft may be connected to the low speed by either bevel gears, when the shaft would be horizontal, or, if the machine is of a type with fixed rails and the main shaft requires to be raised and lowered to permit the revolution of the table, then bevel gears are impossible and a high speed vertical shaft with spur gears is necessary. With ordinary gear ratios, this will give a vertical shaft speed of somewhere from 50 to 150 revolutions and a vertical motor can be considered, as in the installation which we are describing.

The third scheme would be to apply bevel gears to the high-speed vertical shaft and on the horizontal shaft revolving at, say, 200 or more revolutions, the motor could be direct connected. Machines of this type are in successful operation.

Another scheme is to use a belted motor driving the last mentioned horizontal shaft, when, due to the motor being belted there are no particular limits as to the motor speed required. This last plan has been in use in this plant for some fifteen years and is in fact in quite general use in all plants.

In changing over this plant from 25 cycles produced locally to the 60-cycle central station power, (the 25-cycle system having been installed something over fifteen years ago) it was particularly necessary to consider the use of new motors rather than the use of the old motors with a frequency changer. This being the case, any type of motor could be selected; but due to mechanical troubles with belts, pulleys, bearings and bevel gears, which originally were designed for 300 and 500 h. p. but now with improved methods of manufacture, were loaded to peaks of 500 and 700 h. p., it was considered necessary to use a drive which would eliminate all bevel gears and belting. This decision reduced the methods of driving to the first two mentioned.

It is needless to point out that a motor revolving at 10 revolutions is a very large and expensive machine and nearly impossible at 60 cycles, although quite practical with the aid of a lower number of cycles and a frequency changer. Some of the saving due to a motor of this kind would be the reduction in size of the large pits required under the machines, formerly necessary to house the belted motors and various arrangements of gearings. Such a saving, however, could not be obtained except in a new plant designed particularly for motors of this kind and as it would also involve the

complete redesigning and rebuilding of the machine itself, it would mean a large loss in production; the machine being in use 144 hours per week. It was, therefore considered unfit for this case.

The second scheme of the vertical motor revolving at somewhere between 50 and 150 revolutions was found to be very satisfactory, if synchronous motors were used, both from an efficiency and a financial point of view.

Following is the problem which the motor manufacturers were called upon to meet:

Motors were to be three-phase, 60-cycle, 2200-volt, one rated 700 h. p. at 68 revolutions, and the other 500-h. p. at 106 revolutions; temperature rise being 50 deg. cent. and continuously loaded. Mechanically the motors were required to fit present pits and, specifically, not to exceed a certain diameter, approximately 15 ft. on account of their striking the main shaft or necessitating excessive cutting away of the concrete pillars supporting the upper part of the machinery. The stators were to overhang the pit without support. One bottom combined guide and thrust bearing was called for, this to be attached in the simplest possible manner to what remained of the concrete

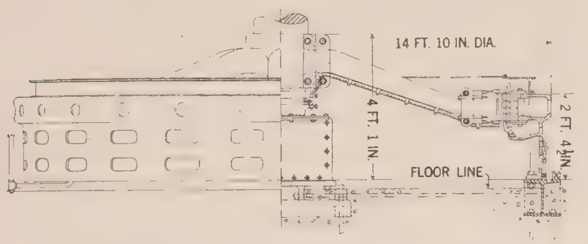


Fig. 2—Cross-Section, Synchronous Motor for Polishing Machine

after the block supporting the vertical shaft had been cut off to a level with the floor. The motors would be synchronous with 250-volt external excitation, self-starting and, when thrown directly across the line, were to develop sufficient torque to start. Due to the load at this plant being practically 95 per cent synchronous, unity power factor only was required.

Referring to the illustration, in Fig. 1, may be seen the manner in which the above specifications were carried out. The tooth reaction on the large motor is on the order of 45,000 pounds, which required the use of an 18-in. shaft to avoid excessive deflection causing unsatisfactory operation of the pinion and gear, or possible rubbing in the gap. The shaft is in two pieces, the idea being that pinion trouble, which has occurred in the past, could be quickly overcome by removing the top half of the shaft. The stator frame (Fig. 2) was made sufficiently deep to act as a girder in a vertical direction to take care of the overhang. The thrust bearing of the spring type (Fig. 3), was set upon a sole plate imbedded in the concrete floor, with arrangements to shift the bearing sideways and allow a lining-up of the gear teeth and similar arrangements provided on the stator frame to adjust the air gap. The resultant side-pull at the bottom of the shaft due to reaction at the pinion, while not great because of the relative ratio of the lever arms, was, nevertheless, a considerable amount to be added to by variations in air gap, and this side thrust was brought quite low on the bearing due to the fact that the thrust bearing is vertically rather thin.

The rotor spokes were made in umbrella type, bring-

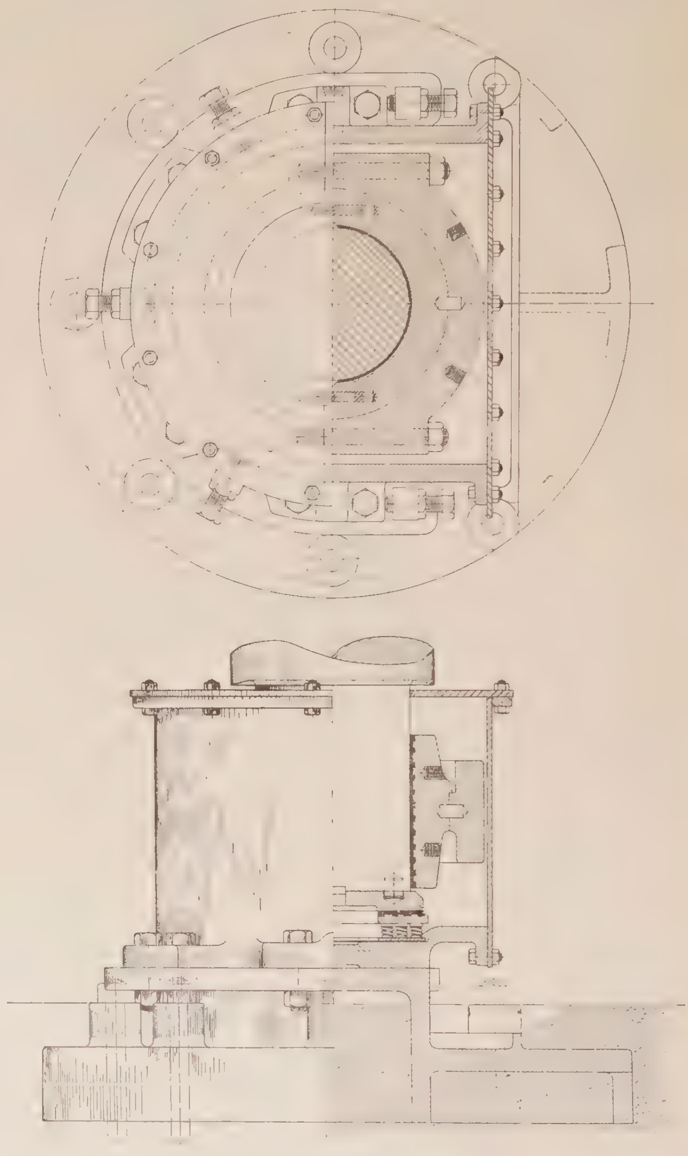


Fig. 3—Enlarged Views of Bearing of Motor Shown in Fig. 2

ing the center line of the active part of the motor down nearer the floor and quite close to the center of the lower bearing, the effect of this being that even considerable wear of the upper bearing would not cause any material change in the air gap.

It will be seen from Fig. 3 that by taking the front plate off the bearing and raising the shaft slightly by means of jacks under the rotor rim, the bearing plates can if necessary, be very quickly removed and replaced.

These motors have been unusually successful in operation being put into regular continuous service within an hour or two after first being started. They show very high efficiency in spite of the low speed, the 700 h. p. being 92.3 per cent and 92.8 per cent for the 500 h. p. The motors are thrown directly across the line by means of a special contactor which is designed to have approximately 15,000-amperes rupturing capacity in the event of a short circuit; but this is sufficiently rapid in operation to permit of a jogging motion being given, so that the table may be slightly turned to bring the wheels above the track. The field is automatically closed by a definite time limit relay, set at something less than thirty seconds and put into operation by the throwing on of the stator current. The starting current, while not a limiting feature, is quite satisfactory, being less than the guaranteed 280 per cent of normal for the 700 h. p. and 250 per cent for the 500 h. p.

In conclusion it might be stated that we are unable to locate any similar slow speed vertically geared synchronous motors in the United States, and that apparently those described herein are unique in several particulars.

High Tension Substation

With reference to the central station power supply, the Union Electric Light and Power Company, of St. Louis, has built a double-circuit steel tower line, operating at approximately 115,000 volts from the Cahoka Power Plant to Crystal City, a transmission distance of 34 miles.

The power being purchased at 110,000 volts, the glass plant was required to build a complete receiving and transforming substation and other parts of the system required to receive this power from either or both of the transmission lines, the step-down transformer banks to be considered as a unit with the line. In other words, there were no cross connections.

The high-tension oil switches were required to have upwards of a million and a half-kv-a. rupturing capacity and their bushings, as well as the transformer bushings, were required to have at least leakage surface equivalent to that supplied on 132,000-volt equipment, because of the prevalence of coal smoke and similar dirty conditions of the atmosphere. The power factor of the load had to be above a certain amount, but this was more than met in that the bulk of the load consisted of synchronous apparatus.

From the consumers' viewpoint, in designing the high tension substation the problem was presented of locating the station on a limited piece of ground adjacent to other high buildings and railroad tracks, compelling the transmission line to make a span of over 1600 feet across a number of the railroad yards of the company on which locomotive cranes were in constant use. This requirement in itself forced the use of a dead-ending tower approximately 135 ft. above the ground.

The peak load of the plant, amounting to 7500 kw. or more, together with some possible extensions, called for the consideration of 10,000 kv-a. banks. With these fundamental requirements in view, the substation shown in Fig. 4, was designed and built.

It will be seen that the two transmission lines are dead-ended on the upper platform of the tower and the

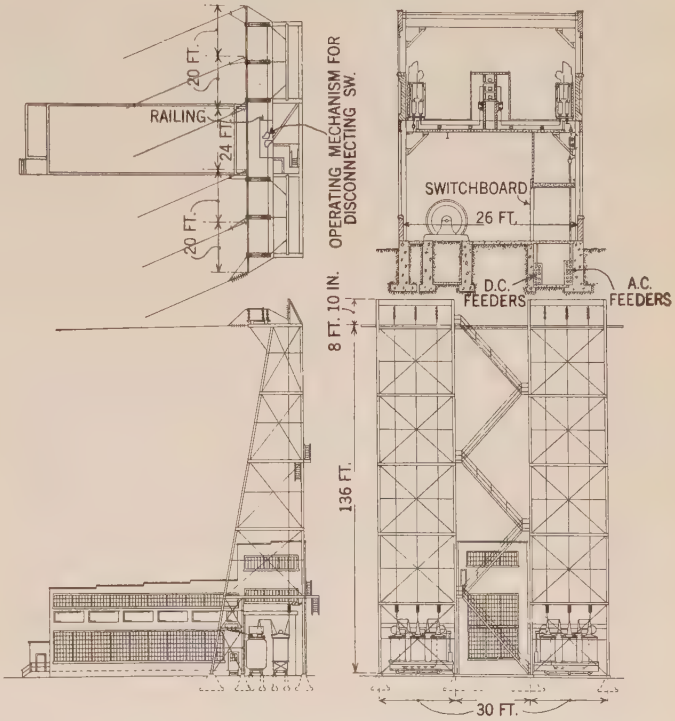


Fig. 3 a—High Tension Transformer, with Four-Row Tubular Tank

wires are 20 feet apart. The circuit is then carried through motor-operated pole top switches having a single break six ft. long. The circuit continues down the inside of each of the outside sections of the tower, the wires being eight ft. apart, and having some five-ft. clearance to ground, supported at the upper end by strain disks, and at the lower end by a rigid insulator

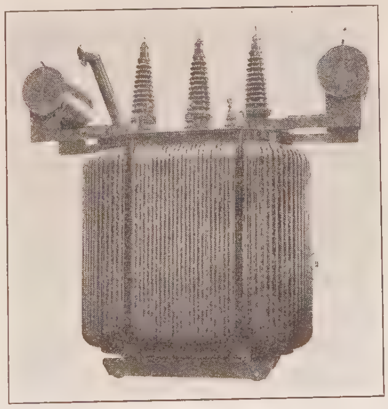


Fig. 4—View of 110-Kv., 20,000-Kw. Substation

hinged on the steelwork of the tower to swing in a vertical direction and clamped to the wire on the outside end. A weight of approximately a thousand pounds is attached to the head of the insulator, to put sufficient tension in the vertical wire to prevent side motion.

Running through the base of the tower are two standard gage tracks, on one of which are two 130,000-volt oil switches and on the other two 10,000-kw. three-phase, circular-coil Core type transformers, provided with conservators and two-in. tubes for cooling. It will be noticed that the line side of the oil switch is within a few feet of the steadying insulator before mentioned, the relative arrangement being such that if the line should burn off at the upper end, the insulator and the weight are expected to swing downward and thus prevent damage to the oil-switch bushing. The oil switch and the transformer are as close together as possible so that no high tension insulators are required between the two. The 2300-volt secondaries are connected to the leads going into the building by short lengths of flexible cable.

The central part of the tower, approximately 28 ft. square and 50 ft. high, constitutes the repair shed. Roll-up doors, 20 ft. wide and 23 ft. high, admit both the oil switch and the transformer to the building, where a 25-ton trolley of the standard type used on overhead cranes, operates on a fixed track at right angles to the transformer track. This crane is provided with a motor for the lift and hand motion for the cross travel. The lifting speed is approximately two feet per minute, which is very handy for transformer repair work.

The outstanding points of the high-tension part of the substation lie in the fact that only twelve high-tension insulators are in use outside of the apparatus bushings; 20,000 kw. with switching and repair facilities is located on approximately 2000 sq. ft. of ground; and the transformers, we understand, are the largest, or among the largest, provided with tubes, that have ever been shipped filled with oil.

The low-tension part of the substation is a two-story building on the second floor of which is the 2300-volt bus structure consisting of the usual concrete and brick arrangements, with disconnecting switches connected to the H-type oil switches, arranged along each side of the building by one-quarter by four bars run under the removable steel floor and above the four in. concrete ceiling. On the first-floor two 1200-kw. motor generators, with space for a third, are installed.

Along one entire side of the building is the remote control a-c. and the hand-operated d-c. switchboard of the usual design. A mezzanine floor located back of the panels and slightly above them, is provided to give access to the outgoing disconnecting switches and to cover part of the control conduit. There is also a partition wall running from the top of the switchboard panels to the ceiling which contains the balance of the control conduit and also protects the balance of the station in the event of a cable pothead or a current transformer blowing up. At the top of the panels is located a pull box, about 4 in. by 12 in. and extending the entire length.

In this connection it will be seen that considerable expense has been incurred to place barriers throughout the low tension bus bar system, as it was considered that short circuits of about 250,000 kv-a. might occur.

The outgoing a-c. feeders, in three-conductor leaded cable, go down the side of the building from above the mezzanine floor and, in fibre ducts encased in concrete, into the pit underneath the switchboard. The d-c. cables of the same general description enter the ducts on the other side of this pit immediately under the switchboard panels.

Substation Equipment

High-tension disconnecting switches:
- 2—L G 119—154 kv. on 135-kv. insulators, motor operated.

High-tension oil switches:
- 2—F H K O—72 C—135,000-volt, 400-amperes, Solenoid operated.

High-tension transformers:
- 2—Type H. Circular Coil 10,000-kv-a.—110,000-2300-volt, three-phase, 60-cycles air cooled by 2 in. tubes, with conservators.

High-tension oil storage and treating system:
- 2—12,000 gal.
- 1—7 in. Filter press.

High-tension repair shop:
- 1—25-ton Crane.

Low-tension oil Switches:
- 2—3000 amperes, 15,000 volt.
- 2—1200 " "
- 4— 800
- 8— 500
- Type H-206 and 203.
- 6—Motor-generator starting switches,—F. K. 132-A & B.

Bus Insulators, 15,000 volt, heavy duty.

Motor generators:
- 2—1200-kw. 250-volt, with synchronous motors.

Switch board:
- 12—a-c. Remote Control Panels,
- 21—d-c., Manual.

Above electric equipment by General Electric Company,

Sub-station peak 10,000 kw. annual kw. h., 50,000,000.

Plant Equipment:
- 8—700 H.P. synchronous motors, G. E. Co.
- 8—500 " " " "
- 1—500 H. P. synchronous motors for air compressors, G. E. Co.
  - Control for above. " "
- 675 h. p. induction motors—for pumps—G. E. Co.
- 950 h. p. motors various uses,
- 500 Motors, (approx) 250-volt, D. C. for all other uses.
  - 500 k. w. total lighting transformer.
- Main distributing system—7 miles 3 conductor lead Cable mostly underground.

Frequency Multiplication
Principles and Practical Applications of Ferro-Magnetic Methods

BY N. LINDENBLAD[1] and W. W. BROWN[2]
Non-member Non-member

INTRODUCTION

MANY of the principles involved in the multiplication of frequencies by the use of highly saturated iron cores have been established by early investigators in the field of radio engineering. A number of articles on the subject have been published by various investigators, although very little information about the performance of frequency multipliers under load conditions was found.

1. E. F. W. Alexanderson, *Magnetic Properties of Iron at Frequencies up to 200,000 cycles.* TRANSACTIONS A. I. E. E., November, 1911.
2. Dr. A. N. Goldsmith, Radio Frequency Changers. *Proceedings* I. R. E., March, 1915.
3. J. Zenneck, A Contribution to the Theory of Magnetic Frequency Changers. *Proceedings* I. R. E., December, 1920.
4. T. Minohara, Some Characteristics of the Frequency Doubler as Applied to Radio Transmission. *Proceedings* I. R. E., December, 1920.
5. M. Latour, Static Frequency Multipliers for the Production of Very High Frequencies in Radio Telegraphy. *Revue Generale de l'Electricite*, July, 1922.
6. K. Schmidt, High Frequency Sender for Radio Telephony. *Elektrotechnische Zeitschrift*, October, 1923.

Frequency multipliers were investigated in connection with the development of the 200-kw. Alexanderson radio system; however it was found entirely feasible to build 200-kw. alternators which would generate directly the frequencies required. During these and other investigations, frequency multipliers were used to generate a wide range of frequencies in a study of transmission phenomena, and very satisfactory performance of the multipliers was obtained. Simplified circuits were developed and communication established between Schenectady, New York, and New York City with very small amounts of power. Both telegraphy and telephony were used.

This paper describes some of the results to date of a joint investigation by the Radio Corporation of America and the General Electric Company, and is intended to present, in a condensed form, physical conceptions of the operation of iron-cored frequency multipliers. The main object of the investigation is to determine the possibilities of increasing the usefulness of the 200-kw. Alexanderson alternators. Results, to date, include a number of improvements in the design of frequency multipliers and arrangement of circuits, and indicate that frequency multipliers may be used advantageously with 200-kw. alternators to meet special requirements. Indications are that frequency multipliers could also be used in industrial applications where relatively large amounts of power at relatively high frequencies are required.

PRINCIPLES OF SINUSOIDAL AND SHOCK EXCITATION

Any periodic curve is the resultant of a number of sinusoidal curves of various amplitudes and frequencies, and these can be separated by mathematical treatments in accordance with the well known Fourier's theorem. The periodic fluctuations of the distorted magnetic field in frequency multipliers has thus been studied, affording a basis of incomparable value in such work.

In practical work, with iron-cored frequency multipliers, a distinct line may be drawn between two methods of excitation,—the sinusoidal and the shock methods. Considered theoretically, the former represents a condition in which the resultant flux curve consists, in its elements, of only two sine curves, the fundamental and the harmonic desired. The resultant flux curve obtained when using the shock excitation method may be resolved into a greater number of elementary waves.

The sinusoidal method is more and more nearly approached as the desired harmonic is supplied with new energy during the greater part of the duration of its period. In the well known case of doubling the frequency of the fundamental by means of a double unit arrangement, the sinusoidal method is predominant. The arrangement consists of two separate multipliers, each saturated to the correct degree by direct current and connected in such a way that a distortion of the magnetic flux takes place alternately in each unit for each half-cycle of the fundamental. The magnitudes of direct current and alternating current can be so chosen that the voltage induced by the distorted field is sinusoidal and is the second harmonic of the fundamental frequency.

As the art of the ferro-magnetic method advanced, it was found by various investigators that higher efficiencies could be obtained by the shock excitation method; that is, instead of obtaining an induced e. m. f. of sinusoidal character by the sinusoidal method, it is better to force the device to its maximum efficiency by shock excitation. The output of a given multiplier, when shock excited, has been found in nearly all cases to be larger than when adjusted to induce a sinusoidal e. m. f.

1. Radio Corporation of America, New York, N. Y.
2. General Electric Co., Schenectady, N. Y.

Presented at the Spring Convention of the A. I. E. E., at St. Louis, Mo., April 13-17, 1925.

It was found that, when doubling a fundamental frequency, the difference between the two methods from an efficiency and output standpoint was not very great. However, as the multiplication ratio was increased, the efficiency of the sinusoidal method dropped very rapidly. When using the sinusoidal method at higher multiplication ratios, a number of units are required, combined in cascade, and the overall efficiency is the product of the efficiencies of the individual stages. On the other hand, when using the shock excitation method, the desired multiplication is accomplished in one stage, and, though the efficiency of this one stage may be lower than the efficiency of one of the stages in cascade, the overall efficiency will usually be higher.

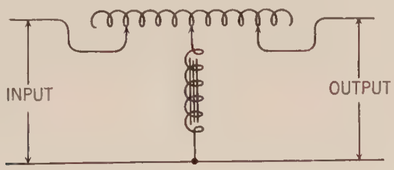


Fig. 1—Frequency-Multiplier Circuit

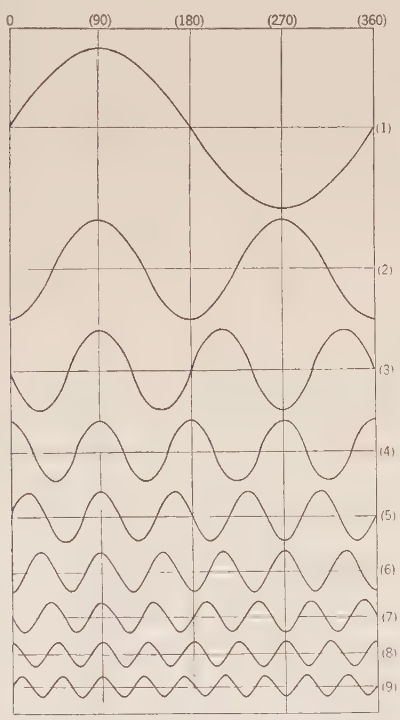


Fig. 2—Phase Relations Between a Fundamental Wave and Various Harmonics

When using the shock excitation method, the energy is supplied to the harmonic during a relatively shorter time period and assumes a transient character. This introduces two problems which become more difficult to solve as the multiplication ratio is increased.

The first problem was manifest in the inability to load the system. The fundamental frequency circuit would not oscillate unless the kv-a. of the circuit was made relatively large, since using relatively low kv-a. in the circuit, little energy is stored and the disturbance at the time of the energy transfer to the harmonic circuit is too great. Also by employing a circuit of reasonably large kv-a., when working with transient impulses, a cushion effect is obtained across the multiplier to allow the induced voltage peaks to develop. This is accomplished by the resonant circuits connected to the multiplier being series circuits of relatively high inductive reactance. A series-tuned circuit has an infinitely high reactance to transients, whereas a parallel-tuned circuit has zero reactance to transients. The reactance in the resonant circuit also prevents the fundamental or some undesirable harmonic that may accidently develop from entering the output circuit. In the case of doubling the frequency, the reactance required to separate the two frequencies needs to be larger than would be required by any of the reasons previously given. To avoid an unduly large reactance for this case a circuit was developed by E. F. W. Alexanderson, which is shown in Fig. 1. The circuit consists of an auto-transformer arrangement, utilized in such a way that the section from one end of the coil

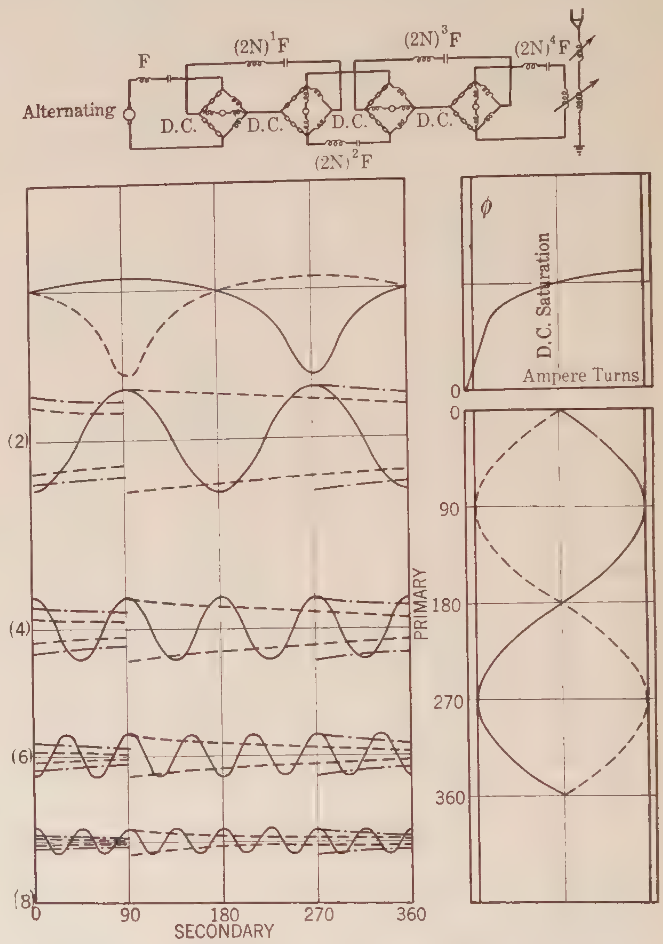


Fig. 3—Half-Cycle Excitation Multistage Arrangements of Frequency Multipliers for the Production of Even Harmonics

to its intermediate tap comprises the inductance in the resonant circuit for the fundamental frequency. The remaining portion of the coil from the intermediate tap to the opposite end comprises the inductance of the resonant output circuit. The intermediate tap of the coil to which the multiplier is connected is chosen so that the voltage induced in one section from the other section neutralizes the voltage impressed on the intermediate tap from the multiplier. For circuits arranged for higher multiplication ratios, this arrangement ceases to function on account of the pronounced transient character of the energy transfer. This

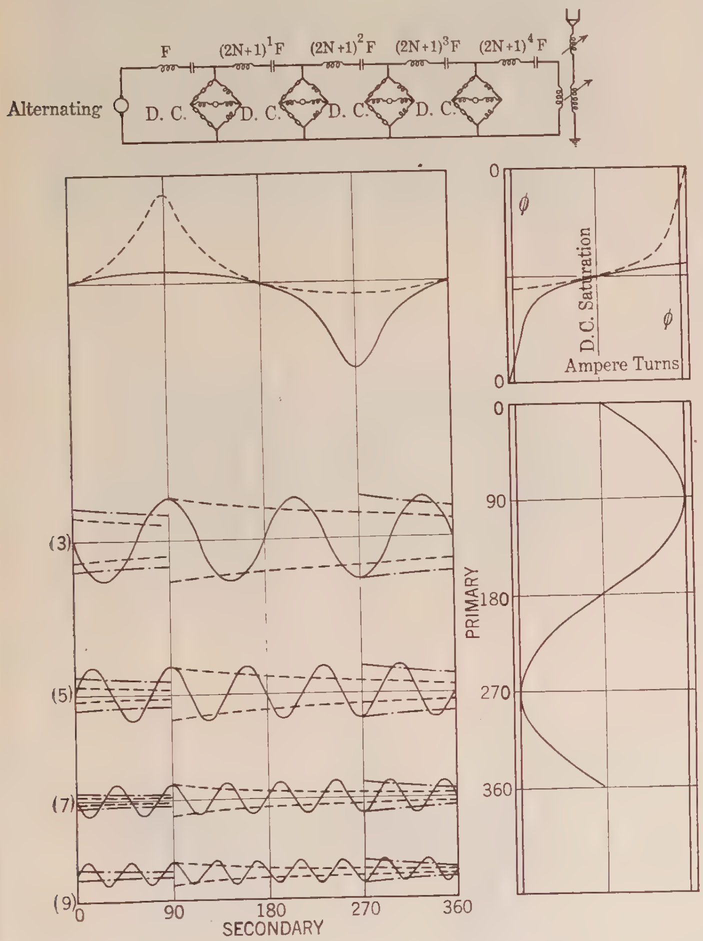


Fig. 4—Half-Cycle Excitation Multistage Arrangement of Frequency Multipliers for Production of Odd Harmonics

circuit is not required for higher multiplication ratios, as the difference between the input and output frequencies is so great that ample separation is afforded through simple tuning.

The other problem introduced by the shock excitation method, which increases in difficulty with increased multiplication ratios, is the damping effect in the output circuit. Difficulties due to this phenomenon were first encountered in a transmission test on a wave length of 3200 meters (94,000 cycles) which involved quadrupling a fundamental frequency of 23,500 cycles. The test was very successful in all respects, except that it was difficult to obtain a clear note at the receiving station. The reasons were that the oscillations were damped and declined as a logarithmical function, thus giving a signal not as clear as obtained from a wave of constant amplitude. Side frequencies were also partly responsible for the impurity of the note. These side frequencies constitute a quite serious problem in radio applications, as they are the results of characteristics inherent in the circuit. If a circuit has more than one degree of freedom, the oscillations, when left without a continous guiding e. m. f., degenerate into oscillations corresponding to the various degrees of freedom of the circuit. The conditions are generally not improved by loosening the coupling between the circuits, as this merely tends to bring the various degrees of freedom closer together. It was therefore realized that, in order to improve the arrangement so as to give it real commercial value, the method of energy feed must be greatly improved.

As has been pointed out, the side frequencies and the damping effect were the results of too infrequent energy impulses. Some improvement could be obtained by means of a relatively large energy storage or tank circuit, but such an arrangement would consume relatively large amounts of power. A much better way would be to increase the number of impulses and thereby provide a more frequently occurring guiding voltage for the oscillations.

Circuit Improvements for Shock Excitation

If the multiplication ratio is not too high, it is sufficient to obtain one impulse from each half-cycle of the fundamental. The connection arrangements to obtain the correct phase combinations of the harmonics are indicated in Figs. 2, 3, and 4. It should be noted that the circuits and relations differ for odd and even harmonics. When working with higher multiplication ratios, the one impulse from each half-cycle of the fundamental is not sufficient. One arrangement by which a greater number of energy impulses can be supplied to the harmonic is by the use of polyphase power supply. A similar arrangement has been suggested by Mr. Dornig[3], who also offered a method of combining a harmonic of one fundamental frequency with a harmonic from a different fundamental frequency. The use of polyphase or equivalent excitation is vital in circuits to transfer large amounts of power, as the reactive circuits can be reduced considerably and perhaps eliminated entirely if there is an energy impulse for each half cycle of the harmonic.

Advantages of "Dip" Method

Regarding the methods of exciting the multiplier and utilizing the bend of the magnetic curve in the most efficient manner, it has been found advantageous

3. Contribution to Frequency Transformation by Means of Iron Core Inductance, *Elektrotechnische Zeitschrift*, Vol. 45, No. 42, October 18, 1924, pp. 1107-1108.

to employ direct-current excitation regardless of whether the harmonic is an odd or an even multiple of the fundamental. While it is true that odd harmonics can be produced without saturating the multiplier with direct current, a considerable increase in efficiency is obtained by using direct-current excitation. The reason is that when using direct-current excitation a much smaller alternating component can be used and a large portion of the iron losses eliminated. This is easy to realize by reference to a *H-B* curve of iron. When the iron is already saturated with direct current to a point above the bend of the curve, only so much alternating current need be superimposed to produce a "dip" in the flux intensity. The dimensions of this "dip" are determined by the harmonic desired. Thus the iron loss only occurs at the same time as the "dip" in the flux. During the rest of the time, the iron is fully saturated and the losses relatively small. On the other hand, when no direct current is used, a much larger amplitude of alternating current is required to reach the desired point of flux deformation. Besides, the iron is being worked in an unsaturated state the greater part of the cycle, which results in considerably higher iron losses. The only apparent advantage of the multiplier without direct current for producing odd harmonics is that, by using a single multiplier unit, an impulse is transferred from each half-cycle of the fundamental, whereas, when direct current is used, two multiplier units are required arranged in such a way that the phases of the impulses are correctly combined. However, this latter arrangement adds very little complication to a system.

Advantages of Short Magnetic Path

Theoretical considerations of the design of frequency multipliers indicated a decided increase in efficiency should be obtained by making the diameter of the core relatively small. The reason is that the inducing power of a magnetic field is due to the cross-section of the field, but not to the length of the path. Substantially the same results are therefore obtained with smaller amounts of iron and the correspondingly smaller core loss. In substantiation of this theory, a circuit containing a multiplier having a magnetic circuit 25 in. in length, see Fig. 5, was found to have an efficiency of 66 per cent when doubling. The same circuit, but containing a multiplier having a magnetic circuit 12 in. long, had an efficiency of 78 per cent. Similar effects have been observed by other investigators, but apparently the principles have not been investigated to determine the limits.

To investigate the possibilities of further improvement in this direction, a series of sample units have been made up in which the length of the magnetic circuit ranges from three inches to 3/8 inch. Measurements made on the unit having the shortest magnetic circuit indicated that a stage was reached at which the copper and iron losses approached equality, thus indicating that optimum dimensions had been reached. In this particular case, in quadrupling a fundamental frequency of 23,500 cycles, an efficiency of 90 per cent was obtained. These dimensions are, of course, dependent upon the application of the device and the materials used. Fig. 6 shows a sample multiplier with multiple-turn conductor around the core, and Fig. 7 shows a sample with single-turn conductor. The single-turn conductor is necessitated by the extremely small dimensions of the core.

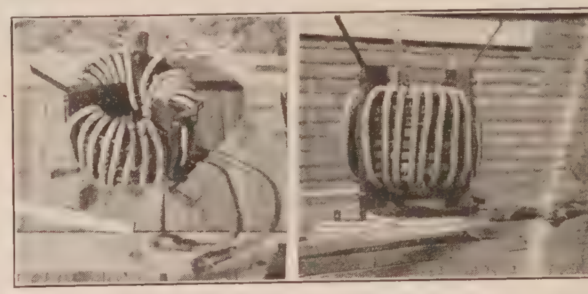


Fig. 5—Two Views of Frequency Multiplier *F M*-3

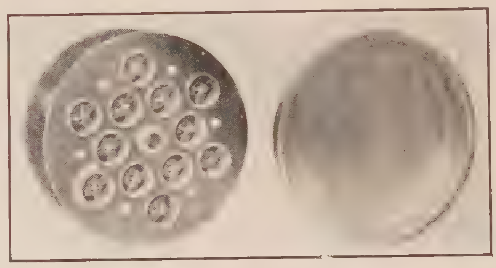


Fig. 6—Frequency Multiplier *F M*-9 (Bottom View With Base Pan Removed

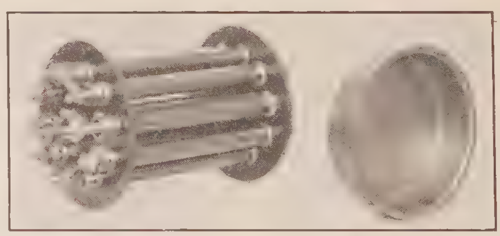


Fig. 7—Frequency Multiplier *F M*-10. 50-kw. Oil Pan Removed and One Section of Core Partly Withdrawn to Show Construction

Core Material

The efficiency and general performance of an iron-cored frequency multiplier is dependent, to a great extent, upon the characteristics of the iron used. In order to make direct comparisons of different grades of iron, samples were prepared in the form of a toroid having the same length of path, same amount of iron,

and with winding of the same conductor and the same number of turns. These samples were immersed in oil for tests. The tests consisted of measuring—

1. The impedance of the various samples at 20,000 cycles which indicates mainly the *B-H* characteristic of the iron.

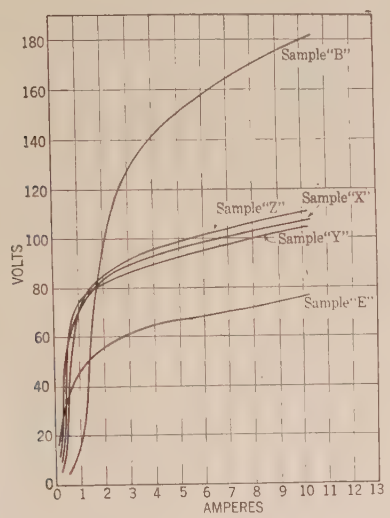


Fig. 8—20,000-Cycle Saturation Curves of Iron Samples for Frequency Multipliers

2. Measuring the temperature rise of the samples at various values of volt-amperes at 20,000 cycles.

The results of these tests are shown in Figs. 8 and 9. Conclusions from these tests, substantiated by results from other tests in which various grades of iron were used in frequency multiplier circuits, are as follows: The iron which has high *B* for a given *H* above the knee

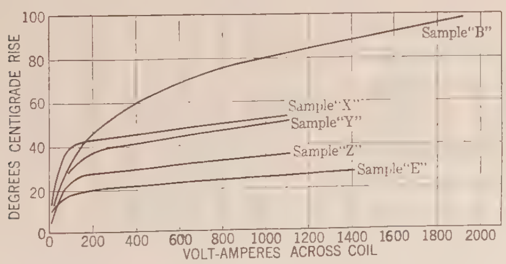


Fig. 9—20,000-Cycle Characteristics of Iron Samples for Frequency Multipliers

of the curve stores more energy at operating adjustment than the iron which has a lower *B* for a given *H*. Stable operation is obtained with iron having a high *B-H* relation. The iron which has a relatively low *B* for a given *H*, while more efficient in operation, has a tendency to be unstable, due apparently to the relatively small amounts of energy stored. A compromise between stability and efficiency is indicated as a most desirable grade, from a practical standpoint.

The intermediate curves in Fig. 8 show the characteristics of an iron which apparently would be best suited. Another advantage of this iron is the relatively sharp bend in the *B-H* curve which should enable the transfer of a greater proportion of the stored energy of the fundamental frequency to the harmonic frequency circuit. This is particularly true in circuits which operate on a principle of shock excitation.

Methods of Measuring Efficiency

Losses in frequency multipliers are being measured by electrical and calorimeter methods. The results obtained by the two methods are in close agreement and are considered sufficiently accurate for practical purposes.

Radio Application

The radio application of frequency multipliers provides a means to greatly increase the usefulness of high power alternators. A 20-kw. frequency-multiplier installation is being made at the Radio Corporation's Transatlantic station at Marion, Mass. This 20-kw. set will be supplied with power from eight armature coils out of a total of sixty-four coils from either of two 200-kw. Alexanderson alternators. This small part of the total capacity of an alternator will reduce the power from the main circuit only 12½ per cent, but will provide a separate transmitter for marine service. This 20-kw. transmitter will multiply a frequency of approximately 25,000 cycles five times in one stage. This set will include the best known features in accordance with the principles outlined herein.

Industrial Applications

The industrial application of frequency multipliers appears to be where relatively large amounts of power are required at moderate frequencies. In the design of salient-pole alternators for relatively high frequencies and for relatively large powers, a nominal limit is between 500 and 1000 cycles. Alternators to develop frequencies appreciably higher than this nominal limit are usually of the inductive type, and, being in a special class, are costly to build and have relatively low efficiencies. It appears entirely feasible to use a 500-cycle salient-pole alternator, and, by the use of iron-cored frequency multipliers, produce relatively high frequencies in sufficient power capacities for many industrial applications.

ELECTRICAL INSTALLATION INSPECTIONS AND TESTS IN AUSTRIA, RUMANIA AND BULGARIA

Testing and inspection requirements differ in these three countries as follows: In Austria, there is no organization charged with these duties, but only licensed electricians are permitted to make installations. In Bulgaria, a special controlling committee inspects and tests each installation before approving it for connection with the line, while in Rumania, where like inspections and tests are required, the work is done by the electrical experts of the municipal administration. No inspection is made in any of these countries by fire insurance companies.

Failure of Disk Insulators on High-Tension Transmission Lines*

HARRISON D. PANTON[1]
Member, A. I. E. E.

A PAPER under the above title was presented by the writer at the Pacific Coast Convention of the Institute in the summer of 1922, and was printed on page 740, Vol. XLI, 1922 TRANSACTIONS of the Institute. This article and the included curves comparing the frequency of failure of the various disks of the assembly with the voltage gradient curve has been of sufficient interest to engineers connected with the high-tension insulator industry for the author to be requested to bring his investigation up to date by including the results of insulator tests of 1923 and 1924.

Although no longer connected with the Yadkin River Power Company, through the courtesy of this company in furnishing the results of their 1923 and 1924 tests, the writer has been enabled to extend the tables to include the 1924 test, and to revise the curves, thus bringing his data up to date and giving a continuous record of the performance of 31,164-disk insulators of the cap-and-pin type, located on the same steel tower line over a period of thirteen years from the time this line was first put in operation to the present.

A brief summary of the physical characteristics of the line under investigation are: 73-ft. double-circuit steel towers, carrying two circuits of 1/0-six-strand hard drawn copper, the three conductors of each circuit being on the same side of the tower; the vertical spacing is 9 ft.; the horizontal spacing, in the case of the top and bottom wires, is 15 ft., for the middle wires, it is 21 ft.; one galv. strand ground wire is carried on the tower peaks; the average span is 680 ft.; the operating voltage 105,000, giving a voltage to ground of 61,000. On the suspension assemblies seven disks of the cap-and-pin type are used, these were manufactured in 1911, and due to replacing these disks on certain other lines, all replacements to date have been made from the disks received on the original purchase. For further data and discussion one is referred to the original article.

In extending the tables and revising the curves, one change was made from the arrangement used in the original article. Originally, three tables were given as the line was insulated with six-disk assemblies for the first three years, the 7th disk being added in 1915, this disk was added in position No. 1,—that is, on the conductor end of the assembly. In the following tables, Tables I and II are combined, and in order that the disks may bear the same position numbers relative to the tower or grounded end of the assembly throughout all thirteen years, and also in order that the disk on the conductor end of the assembly may occupy its proper position, the data is arranged in the tables as if the seventh disk were put on in the No. 2 position. The curves are also plotted using the per cent of failures occurring in each position as abscissa, instead of the actual number of failures as was done in the original article; this change was made to facilitate comparison of the "Rate of Failure Curves" over different periods.

It is to be noted from the curves that the results of the 1923 and 1924 tests have not materially changed the general shape of the curve the relative rates of failure of the various positions in the assembly still being in the order 7, 6, 5, 4, 3, 1, 2. It is also interesting to note in this connection, as is brought out by the "Comparison of Rate of Failure Curves," the tendency of the failure curve to straighten out, the curve covering the period 1912 to 1916 and based on 502 failures being very irregular; for the period 1912 to 1920, based on 2470 failures being less irregular than the preceding, whereas the curve for the entire period from 1912 to 1924, if we leave out No. 2 disk with its relatively small number of failures, has become practically a straight line. As this last curve is based on 5995 failures it should closely approximate the true failure curve.

From Table III it will be noted that the number of defective disks located on the 1920 and 1921 tests were much larger than either the preceding or following years. This somewhat abnormal state of affairs is partly explainable by the fact that the 1919 test, as evidenced by the small number of defective disks located, was probably poorly made, dependable labor being very scarce at that time. This explanation for 1920 is further supported by the fact that if we average the number of defective disks for 1919 and 1920 we get 557, which appears to be what we might expect as the proper number of defectives. In the case of 1921 the very large number of defective disks can be partly explained by two reasons; first, that sixteen months elapsed between the 1920 and the 1921 tests, so that almost two entire lightning seasons were covered by this test; and it is probable that many of these failures are due to lightning; secondly the summer of 1920 was a bad lightning season, and the disks failing due to this cause were located by the 1921 test,—the 1920 test having been made in the early spring. Beyond this, the writer has no explanation to offer of the sudden increase, followed by a decrease, in the number of defective disks.

1. Consulting Engineer, Raleigh, N. C.

Supplement to paper presented at the Pacific Coast Convention of the A. I. E. E., Vancouver, B. C., August 8-11, 1922.

For the information of those who do not care to look up the original article on this subject, it will probably be well to state that only suspension assemblies are considered, and that only defective disks located on the annual routine test are included. The reason for this is that when a breakdown occurs the entire insulator assembly is often replaced notwithstanding the fact that the broken down assembly may still contain several good disks. For this reason, disk failures resulting in actual cases of line trouble are not included.

Now that the data in this article have come to the point where they covered thirteen years of consecutive service by 31,164 disks, and analyses as to position in the assembly 5995 failures, it is felt that the time covered and the number of failures studied is sufficiently great to make the rate of failure curve deduced a very accurate indication of the relative rates of failure of the disks in the various positions of a seven-disk assembly. The interesting point to the author, as stated in the original article, is that the voltage gradient curve would lead one to believe that frequency of failure would be in the order Nos. 1, 2, 3, 4, 7, 6, 5; instead of which we find it to be in the order Nos. 7, 6, 5, 4, 3, 1, 2. This state of affairs leads one to wonder whether or not the efforts being made to equalize the voltage drop over the various disks of the assembly by means of pipe shields, or using larger disks on the lower third of the assembly, are not misdirected. It would seem to show that an effort should be made to devise corrective measures to reduce the number of failures on the grounded end of the assembly.

The tables and curves follow:

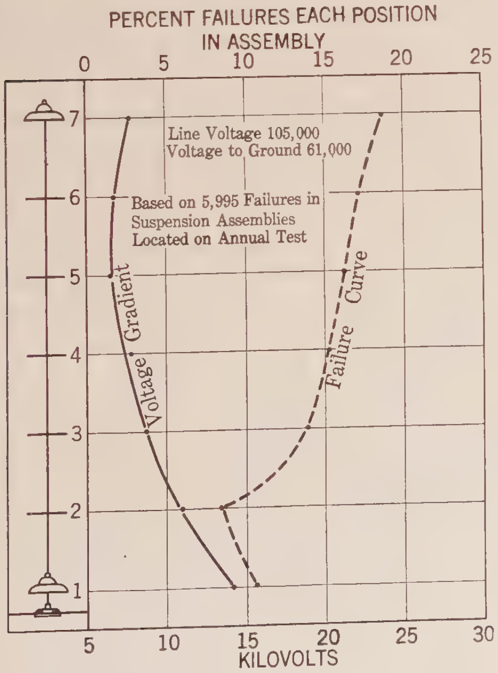


Fig. 1—Comparison of Rate of Failure Curves for 31,164 Cap-and-Pin Type Disk Insulators, 1912-1924

TABLES I AND II COMBINED

Total No. of disks of cap-and-pin type on suspension assemblies prior to 1916,—26,712; after 1916,—31,164.

Disk No.	Top Wire	Middle Wire	Bottom Wire	Total	Failures as per cent Total No. Disks, each Position	Per cent of Failures each Position
1	209	191	223	623	14.0	10.4
2	181	157	159	497	11.1	8.3
3	272	317	248	837	18.8	14.0
4	380	292	244	916	20.5	15.3
5	373	325	276	974	21.8	16.2
6	412	337	284	1033	23.2	17.2
7	440	360	315	1115	25.0	18.6
Totals	2267	1979	1749	5995	——	100.0

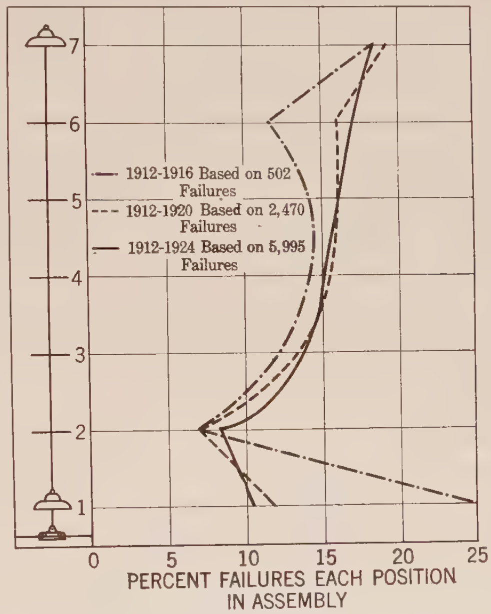


Fig. 2—Voltage Gradient and Rate of Failure Curves for 31,164 Cap-and-Pin Type Disk Insulators, 1912-1924

TABLE III

Total Nȯ. cap-and-pin type disks on suspension assemblies prior to 1916, 26,712; after 1916,—31,164.

Disk No.	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924
1	14	26	30	54	51	41	42	36	100	96	84	49
2	—	—	—	21	20	44	22	69	111	57	66	77
3	8	22	11	20	48	63	40	124	237	80	81	103
4	8	22	16	26	44	85	60	127	254	71	89	114
5	9	23	10	30	55	88	67	116	272	80	100	134
6	5	14	19	21	52	88	40	160	295	91	128	120
7	3	23	24	43	71	103	42	170	303	86	90	157
Totals	47	130	110	215	341	512	313	802	1572	561	638	754
Per Cent of Total Disks	0.2	0.5	0.4	0.7	1.1	1.6	1.0	2.6	5.1	1.8	2.1	2.4

BROADCASTING IN JAPAN POSTPONED

It was originally planned that broadcasting in Japan would begin on March 1, but according to a cable from Acting Commercial Attaché Frank Rhea, Tokyo, this has been postponed at least two weeks.

Electric Lighting Equipment on Automobiles

BY J. H. HUNT[1]

Member, A. I. E. E.

Synopsis.—*The convenience and flexibility of electric lighting is the principle reason for the development of the present type of automotive electrical equipment. The conflicting requirements of good illumination for the drivers and the elimination of glare for the driver of the on-coming car have lead to the adoption of tight directing devices according to specifications drawn up by the I. E. S. Lights conforming to these specifications give good results under ideal conditions but under bad road and car springing conditions cause a great deal of discomfort to the drivers of on-coming cars and considerable dissatisfaction with the results.*

There is a great need of improved result. The possibility of obtaining improved result by the use of polarized light, by the means of light filters, by the use of more diffused light, is discussed very briefly.

The convenience and flexibility of electric lighting is one of the principal reasons for the present universal use of complete electrical installations on automobiles. Electric lighting for automobiles was experimented with from very early days; the first installations provided parking lights from storage batteries, which were removed for recharging, as no charging generators were fitted. Headlights were not used, as the high-efficiency concentrated filament lamp was not available and the current requirements would have been prohibitive with the lamps available. Generator systems appeared with the development of the metal filament lamp, the early generators usually having complicated controls. However, intensive effort followed, and by 1910 generator-charging systems were applied as standard equipment on some makes of cars, to be followed by the complete starting and lighting systems a year later.

The metal filament of the six-volt lamp could be concentrated to such an extent that a very narrow beam could be obtained with a fairly short-focus (1¼ in.) parabolic reflector. This beam gave better penetration than the competing acetylene lamps, although the roadside illumination left much to be desired, which limited visibility when making turns, or when driving on winding roads. The high candle power in the center of the beam, combined with the existance of very little side illumination to aid the driver of oncoming vehicles, caused the public to protest because of glare, and laws were passed requiring dimming when meeting other vehicles.

The problem was studied by committees of the Illuminating Engineering Society and the Society of Automotive Engineers, with the final result of the adoption of the I. E. S. specifications for the distribution of the light from automobile headlamps. This distribution is shown in Fig. 1, which shows the permissible candle power limits of the beam from a single lamp. This distribution curve is naturally a compromise between the needs of the man behind the lamp (who must be able to see a dark object 200 feet ahead on the highway) and the needs of the driver facing the light, who should be able to see the roadway as well as the car in question, when illuminated by his own headlamps, and whose vision must not be impaired or dazzled for an appreciable interval after he passes the others lights. When the headlamp is placed according to the present S. A. E. recommended standard, 36 in. above the road, the light which is at the *B* point, the center of the highest permissible candle power, strikes the road 172 ft. ahead of the car. This is undesirably close, since it causes bright illumination immediately in front of the car, and hinders vision of more distant objects. The light at the *D* point is the light which strikes the eye of the on-coming driver after he has turned aside to pass. The 800 c. p., specified as a maximum, would be considered glaring by an appreciable percentage of individuals, but it does not leave persons of normal vision momentarily blind. It must be remembered that a considerable amount of light, causing no objectionable glare when passing through a clear windshield, will make seeing quite impossible through a dirty windshield, or one covered with drops of water. Everyone could see fairly well with clear windshields, if, at the moment of passing a lighted vehicle, he concentrated his attention on the roadway about to be passed over, instead of glancing at the approaching lamps. Most of the states require that lights be left on full in passing, for investigation has shown that more accidents are caused by lack of conforming to the I. E. S. specifications than otherwise.

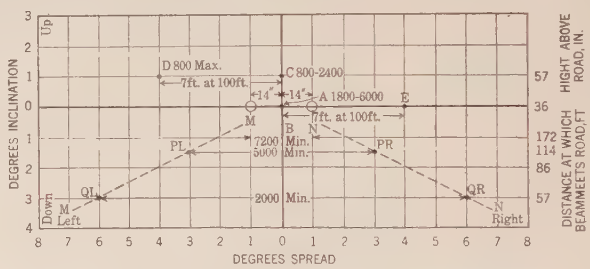


Fig. 1—S. A. E. Specifications for Headlamps

All points on Curves *MM* and *NN* are six ft. from a line midway between and parallel to the axes of the lamps at the point where the beam meets the road.

It must be admitted, however, that while lamps conforming completely to the I. E. S. specifications give excellent results on level, improved roads, combinations of conditions arise wherein the results are anything but

1. Head Electrical Division, General Motors Research Corp., Dayton, Ohio.

Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925.

satisfactory. On rolling roads, or even roads which cause the car frame to rock about a transverse horizontal axis (a thing which often occurs on paved roads with certain combinations of speed and car springs) the high c. p-beam is flashed into and out of the eye of an approaching driver. On narrow, high-crowned country roads, drivers head directly at each other until very near, and when they finally do swerve out, the rear end of the car tends to slide off the road, throwing the beam center of the light up and out to the left, directly into the eyes of any other approaching driver. As a result of this condition and the attendant dissatisfaction, Ohio and Michigan still require the dimming of headlights when within a specified distance of an approaching vehicle.

Today, gas filled bulbs, giving 21 mean spherical c. p., are universally used for headlamps. These consume about 15 watts each. The 6-8-volt (rated) lamps give full c. p. at a terminal voltage of 6.5 volts. The 12-16-volt lamps give full c. p. at 14.6 volts. These voltages are the results of careful survey by the lamp manufacturers to determine the voltages actually existing on cars in service, and are determined by a weighted average, the computation being made on such a basis that the average life would be the designed life of 100 hours. Recently there has developed a very lively controversy between representatives of car manufacturers and lamp manufacturers as to whether the proper basis has been taken for rating lamps. For reasons that will be discussed in the section devoted to batteries, the voltages impressed on the lamps will vary over very wide limits, and since the designed life is very short and based on a voltage much lower than can and does exist on a considerable percentage of cars, unsatisfactorily short life occurs in enough cases to cause car manufacturers considerable annoyance. Some of the car manufacturers are experimenting with bulbs designed for longer life, and a reasonably satisfactory compromise will undoubtedly be worked out.

From the illumination standpoint, the effect of variation of voltage upon candle power, and, incidentally, upon glare, is clearly of great importance. Voltages at the lamp-terminals are found to vary from 5.9 volts to 8.3 volts, the lower voltage being due to undercharged batteries and poor wiring, and the high voltage to charging a very cold battery already pretty well charged. The law of candle power variation with voltage is the same for the automobile lamp as for the house lamp, and it is evident that the candle power at the *D* point of Fig. 1 can greatly exceed the specified minimum if the device has been so designed that 800 candle power is approached for a lamp at normal candle power.

Distribution, approaching that shown in the chart, was maintained for a considerable period exclusively by the use of a properly focused bulb in a simple parabolic reflector combined with a so-called lens, which, as a general proposition, is not a lens at all but simply a circular sheet of glass into which various combinations of prismatic sections have been incorporated. This results in rearranging the distribution of the light from the parabolic reflector, changing from a distribution giving a circular section perpendicular to the beam to one giving a rectangular section, or a very pronounced ellipse, with the shorter dimension vertical. The ideal device would take the beam from the parabolic reflector and, while leaving the full intensity in the horizontal and just below it, would divert the light above the horizontal to the sides and slightly below the horizontal, in conformity with the chart.

The pressure for reduced cost is just as effective in regard to lighting as with respect to any other details on a motor car. To meet this demand, some car manufacturers have recently adopted a headlamp in which the reflector itself has been modified from the parabolic form so as to give the desired lateral distribution of the light without increasing the depth of beam over that obtained by the plain parabolic reflector. No lens is used and it is obvious that there are many ways in which a mirror could be modified to accomplish this result.

One method which is used considerably at the present time is one having the mirror made up of small vertical sections, each of which is generated by a right line moving parallel to itself and following a parabola at its center point. This parabola has its focus at the lamp filament. Very satisfactory results are obtained by use of this principle and such reflectors have the additional advantage of being unaffected by the breakage of glass. High optical accuracy is not maintained in the manufacture of headlamp glassware, and apparently the commercial results of the use of the fluted reflector, in spite of theoretical difficulties in maintaining reflector shape, are as good as for the usual combinations of reflector and deflecting glassware.

The most frequent cause of complaint against the lighting equipment, so far as glare is concerned, is due, however, not to design but to faulty adjustment. The desire for low cost has led to the use of many devices which are not mechanically secure, with the result that lamp bulbs although once properly focused, can shake out of focus; and the driver carelessly continues to use them with this faulty adjustment. Trouble has also been caused by the lens which carries the light bending prisms turning around in the headlamp door, resulting in a light distribution entirely different from that intended. Another reason for the tendency of owners to leave lamps in faulty adjustment has been the difficulty of opening the lamp with some types of designs.

The Society of Automotive Engineers has recently adopted recommended practises calling for securing the lenses in place by a notch interlocking with a lug in the door itself, thus making turning impossible. They have also recommended a type of door more easily opened than the present type with the bayonet lock. The bulb manufacturers have made great progress in improving the accuracy of the lamp filament mounting

with respect to the base of the lamp, making an accuracy of plus or minus 3/64 in. With this degree of accuracy it is possible to design the reflector or the combination of reflector and lens so that with proper design of glassware there will be no necessity for provision for adjustment. Therefore, the distribution of the light would be within the permissible limits so long as the so-called precision lamps are used. To many familiar with the situation it seems that the commercial application of such a system will result in very real improvement for the whole situation. Replacing the bulb too often results in faulty adjustment.

Faulty tilting of the lamp is undoubtedly a cause of considerable trouble from glare. Inspection of the chart of Fig. 1 shows that if the minimum permissible candle power at the B point were raised to the A point, a light exceeding the maximum permissible would be obtained. This shift represents a shift of 1 deg. in tilt. The shorter wheel-base light cars on the market rock more than a degree, front and back, when the load is changed from one passenger to five passengers. If the headlamps have been adjusted to give a satisfactory driving light just inside the limits for one or two passengers, a glaring light inevitably results when the car is loaded. Of course, the lamps are supposed to be adjusted with the full load in the car, but when this is done the bright light of the center beam strikes the road so close to the driver that if he pays any attention whatsoever to lamp adjustment, he is almost certain to raise the angle of the beam.

Tilting headlamps, or rather a tilting of the beam, is a method of eliminating glare much more satisfactory than dimming. This can be accomplished by a mechanical control of the mirror from the dash, (a means which has been employed for several years by certain makers;) or by tilting the part of the mirror which reflects the greater part of the light flux directly back of the bulb. This tilting of the smaller part of the mirror can be accomplished by a combined spring and magnetic control without requiring a great amount of current. Recently a scheme involving the use of a double-filament bulb, having one filament at the focal point and one filament above, has been proposed. The beam is tilted down when switching from the filament at the focus to the upper filament, making a very simple electrical control. This latter method has not yet received universal approval by the state authorities but will probably ultimately find extensive use in one form or another.

Altogether we may say that the headlighting is a phase of the application of electricity to the motor car that is least satisfactory as regards relations between the motor car drivers and the public. It seems reasonable to believe that, as a result of the great demand for improvement, some method will be developed in the comparatively near future to provide real relief to the situation. However, the engineering complications are only a small part of the difficulties at the present time. We have forty-eight sovereign states, each with the right to set up their own inspection service and provide their own rules for inspection and their own regulations. While fortunately these regulating bodies are showing a great disposition to cooperate, it is obvious that they can cooperate only upon the basis of mutual consent. Such being the case, one or two gentlemen of rather fixed opinions, properly placed, can postpone the adoption of a device of merit for a considerable period, since the universal use of the motor car for touring makes it necessary that the equipment on a car sold in Texas shall be satisfactory to the authorities of California and Massachusetts, as well as all states between.

No discussion of the other lamps on the car will be undertaken here, except a brief reference to the so-called spotlight. This is a lamp small in size, but usually of high candle power at the center of the beam. 21 c. p. lamps are generally used with a reflector smaller than that in a headlamp. While it was originally intended to be a manually directed lamp used for picking up direction signs, in states requiring dimming it is usually used to light up the right edge of the road. However, being controllable, it is frequently abused and some states forbid its use entirely. Even when pointed down and to the right, the diffused light from the reflector is often so bright as to cause momentary confusion to the eye of a passing driver when the lamp is mounted high on the left windshield post as is usually the case. Therefore, its presence is somewhat objectionable. If mounted on the right windshield post, its use would be much less objectionable, especially if it were fixed. A committee of the National Conference on Street and Highway Safety has recently recommended that the mounting of spotlights on the left side of the car be forbidden.

Some possible methods of improvement might be mentioned as a matter of general interest, merely to point out possibilities, with no intention to pose as a prophet.

Dimming, tilting the headlight beam, or permanently limiting the height of the beam are all done so that an approaching driver will not be prevented from seeing objects illuminated by his own lamps, but any of these expedients on the part of the meeting drivers limits the vision of each. The most important area to be illuminated is that immediately about the approaching car, particularly the road to be passed over. If each driver were to illuminate this space about his own car, and this could easily be done without glare to anyone, for very little forward-projected light would be required. This could be accomplished by switching from the regular headlamps to special lamps when cars are within 200 or 300 feet of each other. Sufficient illumination of the space about the car, especially at the left, would go far toward compensating for the blinding effect of the headlamps at full brilliancy. Since conditions of the road surface will greatly affect the results from the

illumination stand point, it is doubtful if headlamps can be completely dispensed with by the adoption of such a scheme. An effort has been made in this direction by one car maker, but obviously the scheme cannot succeed unless universally applied, which would require legislation and impose somewhat of a hardship on owners of old cars, the electrical systems of which would not lend themselves easily to its application.

Illumination of the roadway by a permanent lighting system would also take care of the problem, and it is reasonable to expect that the main arteries of travel approaching our larger cities may be so lighted in the not-too-distant future. This is particularly desirable where they carry practically solid lines of traffic for several hours of the day, as is already often the case.

In the early days of the automobile, acetylene lamps were used without nearly so much complaint regarding glare as there is today. These acetylene lamps did not have so great an intensity in the central part of the bulb as that of the electric lamp, but they did give a large amount of side illumination immediately in front of the car, which was of considerable advantage to the driver of the oncoming vehicle. A return to this general type of illumination is being advocated today by several different interests, the claim being that the more uniform light distribution gives a much more satisfactory result, and that the lack of penetration in the center of the beam is more than compensated for by the fact that the driver's eyes need not to be adjusted to the effect of the very bright spot on the road directly in front of the car such as exists with the present type of lamp adjusted to the I. E. S. specifications. On the other hand the rather high intensity of illumination at the side of the car greatly aids the driver of the oncoming vehicle.

Two schemes of obtaining this general result have recently come to the author's attention. One of these, originated by W. D'A. Ryan, involves the use of a shallow, hyperbolic reflector, so mounted in a lamp with a bowl-shaped front glass that the filament itself projects beyond all opaque parts of the lamp and throws a light directly on the side of the road. The maximum candle power in the center of the beam is from 30 to 40 per cent of that obtained with the parabolic reflector, and with such a system, one can read the street numbers on houses being passed and still have the necessary vision of the road ahead. This side illumination is also of considerable assistance to oncoming drivers. Another system for obtaining much the same result involves the use of a large frosted bulb having the filament of greater candle power than is now used, say 36 or 40, mounted in a parabolic reflector. This lamp also gives a very satisfactory side illumination, but has mucn less candle power in the central beam. However, it has the advantage of simplicity and ease of application to cars already in service.

Everything indicates that such types of lighting will be given rather careful consideration in the near future, as there is a determined effort on the part of many influential people to have the whole question of road illumination reopened and the basis of the present approved design reconsidered. Preliminary tests indicate that very satisfactory road illumination can be obtained in this way, the penetration being quite sufficient for road speeds up to the usual 35 mi. per hr., and the side illumination gives an added feeling of security on winding roads, as compared to a narrow concentrated beam. However, a large amount of light rising from the lamps would cause trouble in fog sooner than a beam with a cut-off parallel to the road.

One reason for the adoption of the type of lighting just mentioned is the difficulty of maintaining satisfactory inspection, at reasonable cost, of lamp installed according to I. E. S. specifications. It is claimed that in states where inspection is maintained one can have his lamps adjusted at an official inspection station in one town and be stopped by the police in the next town, a new adjustment being required. Where inspection is not provided for, the results are naturally bad. Ohio required approximately I. E. S. results for a short time, all devices approved being subjected to test. There is every reason to believe that the preliminary inspection was carefully done, but as no inspection was maintained on service equipments, the glare situation became so bad, that the law requiring state approvals of devices was repealed and a dimming law enforced. It is claimed by the advocates of the lighting schemes involving the spreading light with the candle power of the central beam reduced in intensity, that inspection in service would become a very simple matter.

A system of some theoretical interest has been proposed, based on the idea of the use of polarixed light. If the headlamps of a car emitted plane polarized light, polarized parallel to a plane inclined 45 deg. to the vertical with the lower end at the left, and a plate on the windshield having the property of polarizing by absorption, (as in the case with tourmaline), were arranged with plane of polarization at the same angle, it is obvious that a driver would see objects illuminated by his own lamps, and that the light coming directly from the lamps of a similarly equipped car directly facing the first, would be quite completely cut off with no glare. Goggles containing analyzers could be substituted for the polarizing sheet on the windshield. It would probably be commercially possible to polarize the light emitted by reflection without prohibitive cost or weight in the headlamps. High optical properties are required in the system through which the reflected light is returned, and no substance of the necessary properties for a polarizing windshield plate are yet known, while analyzing prisms for goggles are quite out of the question commercially. Therefore, it will probably be some time before such a system could be put in use. One cannot recommend the expenditure of a great amount of money in the development of the required materials, since such a system would require universal legislation

to put it into application, under which conditions the restrictions likely to be imposed would undoubtedly prevent any very great profit in its application. With the proper materials, however, it would seem that the head-lighting problem should be solved.

Glare can also be avoided by other schemes permitting the driver to see the light on the road as thrown by his own headlamps, but cutting out the light of the headlamps of oncoming cars. One method which might be used would be application of colored filters, the two-filter combination being so selected that the amount of light from an ordinary tungsten headlamp passing the filters of two colors, would be so small that the light which would pass through the filter on the headlamp of the one car and then through the filter on the windshield of the meeting car would be minimum and could, therefore, cause very little glare. Thus, if all drivers going east or north, used orange filters in their headlamps to give sharp cut-off, stopping all light of wave lengths shorter than 580 $m\ \mu$ carrying the same colored filters on their windshields, while all drivers in the reversed direction had blue-green filters, cutting off all wave lengths longer than 580 $m\ \mu$, it is obvious that there would not be much trouble from glare.

Roadside markers, informing drivers which filters to use, could be incorporated in the ordinary route markers, and simple means to change from one combination of filters to the other, controllable from the driver's seat, could be incorporated in the design. The dividing line for the colored filters should be chosen for wave lengths longer than that corresponding to maximum sensitivity of the light, since more energy would be available for the longer wave lengths than for the short.

However, compared to the polarized light scheme, and due to the loss of light of the most effective wave lengths, such a system would have the disadvantage of lower efficiency, since filters with a vertical cutoff line are not now or likely to be available, and the cutoff comes close to the point of maximum sensitivity. There would also be difficulty for a small percentage of persons having a very bad form of color blindness, and the affect of the colored light on the roadside might be objectionable to some people, although preliminary experiments indicate that the subjective effect is not as great as one might think. Changed color for danger signal lights would also become necessary although this would be only a minor part of the difficulty which would be caused by the fact that it will be necessary to have universal legislation.

An attempt has been recently made to sell such a system to motor car manufacturers. In this particular system, invented by Karl D. Chambers, a green filter is used for one combination and a magenta for the other, provision being made for the equivalent of two pairs of headlamps, one pair for each color and for means of switching from one colored headlamp to the other when switching filters. To take care of the rather large losses in light flux, due to the fact that only a small part of the visible light is used, 100-c. p-lamps are used in place of the usual 21-c. p. The light flux which passes through the filters on the headlamps is approximately equivalent to 21 c. p. of white light. Road tests have demonstrated that this system does eliminate glare, as when using it one can see the whole of the approaching automobile instead of simply the headlamps as at the present time and also see this automobile in its proper relation to the roadway. The greatly increased current consumption requiring a larger generator and a new current control make an undesirable increase in the cost. This would undoubtedly make it difficult to get the required legislation as the great majority of the cars on the road are of the type where it would be exceedingly difficult to fit generators of the capacity that would be needed.

The schemes which have been mentioned above will undoubtedly seem very wild to the average engineer. However, it appeared desirable to bring them to your attention in the hope that they might stimulate thought on this very important question and possibly cause the development of more practical plans than those discussed. A proper and universally satisfactory solution of the headlighting problem is one of the most important needs in the automobile industry. There is no disposition on the part of the author to seem to criticize unkindly the work the I. E. S. in developing our present specifications. Under ideal conditions there would be very little criticism from anyone. Unfortunately, however, conditions are far from ideal and there is a great amount of adverse criticism. It, therefore, seems necessary to reconsider the whole question, as a joint committee is now doing. If it is found impossible to develop a more satisfactory method of meeting the problem that we now have, we shall at least have convinced more people that this is the fact.

ELECTRIFICATION PLANNED BY THE PARIS-ORLEANS RAILROAD

(Assistant Trade Commissioner Wilson K. Ray, Paris, France)

It is expected that the electrification of the line from Paris to Orleans, the first important step in the electrification of the Paris-Orleans railway, will be completed during 1925.

The complete plan of electrification includes the section from Paris to Brive of the line running from Paris to Tolouse, and the junction lines, one from Saint-Sulpice to Gannat, and the other from Brive to Clermont.

The power for that part of the Paris-Brive section extending from Paris to Chateauroux will be furnished by the central stations of Gennevilliers and Eguzon. The latter station, which is to be equipped with five turbines of 10,000 kilowatts each, will be ready for service toward the end of 1925.

The plant at Coindres, now under construction, is expected to be ready for operation by the end of 1926.

Factors Affecting the Design of D-C. Motors for Locomotives

BY RALPH E. FERRIS[1]

Associate, A. I. E. E.

Synopsis.—*The designer of motors for locomotive service is confronted with at least two limitations; space and weight. For large locomotives, the second limitation may not be of prime importance, but the first must be constantly in the mind of the designer.*

The paper gives a comparison between different types of motor mounting as regards the amount of power which may be developed in the available space with direct current moters. The comparisons are largely qualitative but within reasonable limits are also quantitaive.

The available space between wheels or locomotive side frames is divided into two parts. One of these parts is made up of units which are assumed to be constant within the range considered, while the other part is made up of variables. Expressions for the variables are derived, generally in terms of armature diameter, and constants and variables are then combined into a complete expression for motor output.

The voltage applied to motor commutator, voltage-to-ground, number of poles, peripheral speed and track gage, as well as type of motor mounting are considered in the comparison.

THE object of the following discussion is to develop the proportions of d-c. motors in relation to the available space between wheels or side frames of locomotives.

Two voltages only have been considered, viz., 3000 and 1000 volts, this, not because other voltages, either higher or lower, are not possible or desirable, but simply to give a basis of comparison and eliminate the almost endless number of combinations.

The results should be considered as largely qualitative, but it is believed that the effect of various factors will be shown and in a measure the results are also quantitative. Actual numerical values have been used in most cases with the full realization that exceptions could be taken to these values for special cases, or perhaps even for average conditions, but an honest attempt has been made to place all results on a basis as nearly comparable as possible. The nominal or one-hour rating of motors has been used as the physical dimensions conform more nearly with this rating than with the continuous rating where the type of ventilation is a determining factor.

The paper has been divided into three general sections: first 3000-volt motors; second, 1000-volt motors; and third, discussion of curves and conclusions.

3000-Volt Motors

For purposes of this paper the following classification has been chosen for the 3000-volt motors. It should be understood that the voltage given in the tables refers to the voltage across the commutator and not the voltage to ground which as before stated is in all cases either 3000 or 1000 volts.

1. Axle-hung Gear Drive
   - *a.* 750 Volts
     1. four-pole
     2. six-pole
   - *b.* 1000 Volts
     1. four-pole
     2. six-pole
   - *c.* 1500 Volts
     1. four-pole

2. Frame-mounted, Quill and Gear Drive
   - *a.* 750 Volts
     1. four-pole
     2. six-pole
   - *b.* 1000 Volts
     1. four-pole
     2. six-pole
   - *c.* 1500 Volts
     1. four-pole

3. Frame-mounted, Gear and Side-Rod Drive
   - *a.* 750 Volts
     1. four-pole
     2. six-pole
     3. eight-pole
     4. 10 pole
   - *b.* 1000 Volts
     1. four-pole
     2. six-pole
     3. eight-pole
   - *c.* 1500
     1. four-pole
     2. six-pole

4. Gearless
   - *a.* 750 Volts
     1. two-pole
     2. four-pole
     3. six-pole
   - *b.* 1000 Volts
     1. two-pole
     2. four-pole
     3. six-pole
   - *c.* 1500 Volts
     1. two-pole
     2. four-pole

To illustrate the method of analysis, all the cases for the axle-hung motors, 1 *a*, 1 *b*, and 1 *c*, are worked out in some detail, especially for the 750-volt four-pole motor. The first and second cases, under 4 *b* for the 1000-volt, gearless motor, will also be given in more or less detail. Of the remainder, curves will be shown for all four cases under 3 *a* and first case under 3 *b*, 3 *c*, 4 *a*, and 4 *c*.

Proportion of Space for 3000-Volt Motors, Axle-Mounted

The space between wheel flanges may be divided as follows:

L_t = Total space between wheels or between locomotive side frames

L_c = Length of commutator

L_e = Length of coil extension on ends not including cell extension.

L_g = Length of gear-face

L = Length of armature core iron

L_k = A constant which is made up of the following items:

---

1. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Abridgement of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-13, 1925. Complete copies available upon application at headquarters.

1.	Clearance between gear-case and wheel, front and rear	2.00 in.
2.	Gear-case walls and clearance to gear, wheel side, front and rear	1.75 in.
3.	Gear-case walls and clearance to gear, motor side front and rear	1.50 in.
4.	Gear-case to end-housing, front and rear	0.75 in.
5.	Housing walls, front and rear	2.00 in.
6.	Clearance between front-end housing and commutator V-ring	0.75 in.
7.	Creepage on V-ring	2.50 in.
8.	Commutator groove and clearance between brushes	0.75 in.
9.	Cell extension, both ends	2.00 in.
10.	Clearance between coil and rear-end housing	1.25 in.
	Total	15.25 in.

In order that the foregoing variables and constants may be understood, they are indicated in the diagrammatic long section shown in Fig. 1.

It is realized that the constants as given may be open to question in any particular case, but it is believed they are not far from average conditions, and will at least give, as before stated, a basis for comparison.

Output Equations

It can be shown that the output of a motor may be expressed as follows:

$$\text{kw.} = C\,D^2\,L\,S$$

where

C = A so-called output constant
D = Armature diameter
L = Length of armature iron
S = Speed in rev. per min.

Substituting values given in preceding section in equation (**1**), gives

$$\text{kw.} = (L_t - L_c - L_e - L_g - L_k)\,D^2\,C\,S \qquad (\mathbf{2})$$

But

$$L_c = \text{kw.} \times C_c \qquad (\mathbf{3})$$

Where C_c is a constant depending on brush width, voltage, number of brush arms, and current density in brush.

$$L_g = \text{kw.} \times C_g + C_2 \qquad (\mathbf{4}^*)$$

$$L_e = C_e\,D \qquad (\mathbf{5})$$

Where C_g, C_2 and C_e are constants. The derivations of equations **3**, **4** and **5**, which are a means to an end, will be shown in more detail under the special case of the four-pole, 750-volts per commutator motor.

*Equation (**4**) is only approximate, the following being more nearly correct.

$$L_g = \frac{\text{kw.} \times C_p \times P_t}{s \times N_t}$$

where P_t = Diametrical pitch of gear
S = speed of motor in rev. per min.
N_t = Number of teeth in pinion
C_p = Constant depending on P_t

A value of C_p which will give a fairly conservative gear-face width is as follows:

$$C_p = \frac{32\,P_t}{1 - 0.19\,P_t}$$

Substituting equations **3**, **4** and **5** in **2**, and solving for kw. gives

$$\text{kw.} = \frac{D^2\,S\,C\,(L_t - C_e\,D - C_2 - L_k)}{1 + D^2\,S\,C\,(C_c + C_g)} \qquad (\mathbf{6})$$

If $L_h = L_t - L_k$

Then

$$\text{kw.} = \frac{D^2\,S\,C\,(L_h - C_e\,D - C_2)}{1 + D^2\,S\,C\,(C_c + C_g)} \qquad (\mathbf{7})$$

In order to obtain a comparison, a constant peripheral speed in feet per minute of C_s is taken, in which case,

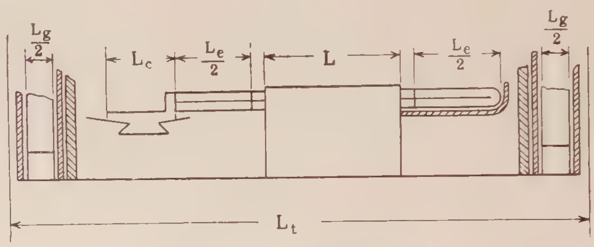
$$S = \frac{3.82\,C_s}{D} \qquad (\mathbf{8})$$

By substitution, a final expression for kw. in terms of D is as follows:

$$\text{kw.} = \frac{3.82\,C_s\,D\,C\,(L_1 - C_e\,D - C_2)}{1 + 3.82\,D\,C_s\,C\,(C_c + C_g)} \qquad (\mathbf{9})$$

Output Constant C

Very often in engineering literature a so-called constant is not a constant at all but is merely a convenient way of combining a number of factors which are difficult to evaluate. Such is the case with the output constant C. This constant C is affected by a number of factors, the principal ones being as follows:



$L_k = L_t - L_g - L_c - L_e - L$

Fig. 1

a. *Slot-space factor.*
b. *Iron loss.*
c. *Pole constant.*
d. *Watts copper-loss per sq. in. of armature surface.*

In general, the output constant increases with increase of armature diameter. It is, of course, practically impossible to give an expression for the output-constant in terms of armature diameter, which will more than approximate the results for any given design. The following empirical expression, however, is used as coming within the limits of accuracy of this article:

$$C = K \log (a\,D - b)$$

Four Pole Axle Hung Motor 750 Volts per Commutator

The axle-hung type of mounting and drive are so common that little or no description is necessary.

Briefly, one side of the motor is supported by either a nose or bar suspension on the truck transom, while the other side is supported directly on the axle, through axle caps and bearings. With this mounting, a certain percentage of the motor weight is carried directly on the axle with no intervening spring.

The output constant for a four-pole, 3000-volt, 750-volt-per-commutator motor may be expressed imperically by the following equation:

$$C = \log (0.385\,D - 1.31)\, 7.65 \times 10^{-5} \qquad (11)$$

Length of Commutator. The length of commutator,

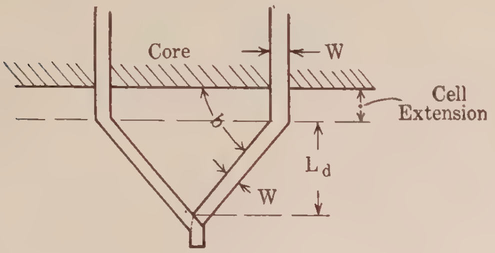


FIG. 4

L_c, for 750 volts per commutator and four brush-holder arms, may be derived as follows:
If

I_t = total amperes to armature
E = volts at motor terminals
f = efficiency

$$I_t = \frac{1000 \times \text{kw.}}{E\,f} \qquad (12)$$

and, if,

$$E = 750$$
$$f = 0.88$$
$$I_t = 1.52 \text{ kw.} \qquad (13)$$

The length of commutator neck cannot be expressed in terms of kilowatt unless the number of parallel circuits are taken into account; but as this introduces a further complication, such a factor will be omitted and the length of neck expressed as

$$\text{Neck} = 0.0024 \text{ kw.} \qquad (14)$$

At 60 amperes per sq. in. in the brush and 5/8 in. brush width, the expression for commutator face, including allowance for brush-stagger, is,

$$\text{Face} = \frac{I_t}{120 \times 0.625} = 0.0203 \text{ kw.} \qquad (15)$$

$$\text{or } L_c = \text{Neck} + \text{face} = 0.0227 \text{ kw.} \qquad (16)$$

Width of Gear-Face. As an emperical approximation of the gear-face

$$L_g = 0.0134 \text{ kw.} + 3.5 \qquad (17)$$

This, for the larger sized motors, will give a gear-face which is somewhat low, and for the smaller sizes, somewhat high.

Coil Extension L_e. In general, the armature slot-depth will vary as some function of the armature diameter. For the present discussion the following relation will be used:

$$D_s = 0.1\,D \qquad (18)$$

where

D_s = Slot-depth

Let

P = ½ the arc of coil-pitch at diameter $(D - 0.1\,D)$

Then for a four-pole machine

$$P = \frac{\pi\,(D - 0.1\,D)}{8}\, 0.95 \qquad (19)$$

The factor 0.95 is introduced to take care of a slight amount of chording.

Referring to Fig. 4, with slot-width W equal to tooth-width at one-half depth of slot and with the coil on the diamond part of the end portion equal to slot-width, the sin of angle b, between iron and coil, will be,

$$\text{Sin } b = \frac{\dfrac{\pi\,(D - 0.1\,D)}{2}}{\pi\,(D - 0.1\,D)} = 0.5 \qquad (21)$$

$$\text{Tan } b = 0.577$$

Therefore- referring to Fig. 4, (22)

$$L_d = P \times 0.577$$

But

$$P = 0.335\,D$$

and

$$L_d = 0.194\,D \qquad (23)$$

If turn at end of diamond part of coil is considered as six per cent of armature diameter and both ends of the winding are included, then

$$L_e = 0.448\,D \qquad (24)$$

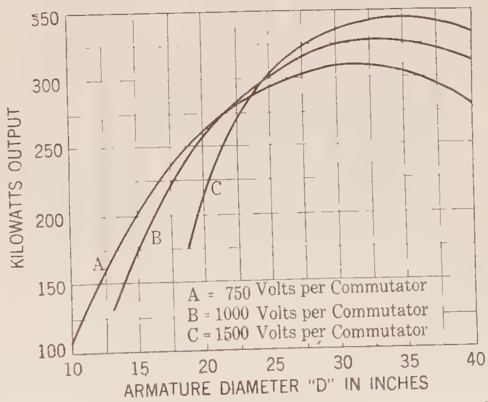


FIG. 5—AXLE-MOUNTED 3000-VOLT, FOUR-POLE MOTORS, 3500 FT. PER MIN. PERIPHERAL SPEED 53.25 IN. TRACK GAGE

TABLE OF CONSTANTS

The following values are, therefore, either constants or assumed constants, at the one-hour rating for a four-

pole 750-volts-per-commutator axle-mounted motor:

$$C_c = 0.0226$$
$$C_g = 0.0134$$
$$C_2 = 3.5$$
$$C_e = 0.448$$
$$L_k = 15.25$$
$$L_t = 53.25$$
$$L_h = 38$$
$$C_s = 3500$$

Substituting equation No. **11** and constants given above in equation No. **9**,

$$\text{kw.} = \frac{(35.4\,D - 0.46\,D^2)\log(0.385\,D - 1.31)}{1 + 0.037\,D\log(0.385\,D - 1.31)} \qquad (\mathbf{25})$$

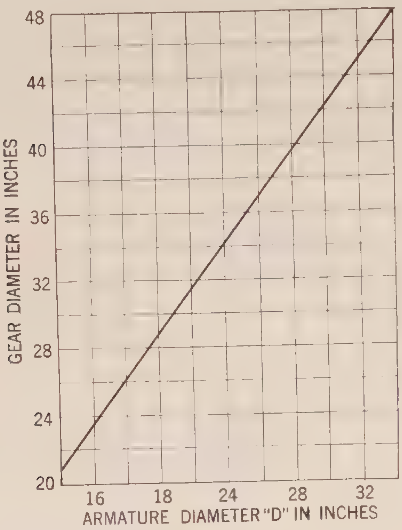


Fig. 11—Axle-Mounted, Four-Pole Motors Gear, Diameter

Equation (**25**) gives the kw.-output of a four-pole 750-volts per commutator motor with double gears. The case for single-end gears will not be considered, as the only difference would be more available space between wheels for active material. In any case, as limitations are being considered, the motor sizes under consideration would, in general, have double gears.

Curve *A* of Fig. 5, is the graph of equation (**25**), and shows the kw.-output plotted against the armature diameter for axle-mounted motors, 750-volts per commutator, at a constant peripheral speed of 3500 ft. per min.

Four-Pole, Axle Mounted Motor 1000 Volts per Commutator

The constants included in L_k will be the same, for a 3000-volt motor with 1000 volts across the commutator, as for a similar motor with 750 volts on the commutator.

The length of coil extension L_e, for the same armature diameter and the width gear-face L_g for the same kw.-output, will also be the same. The length of commutator L_c and output-constant C, will, however, be different.

The length of commutator will be less, due to the smaller amount of current, with the higher voltage.

The output constant for the smaller diameters will be less than for the 750-volt motor due, mainly, to the smaller slot-space factor, but for diameters over 26 in. there will be but little difference.

Taking all the factors into consideration, an expression similar to that given in equation (**25**) was derived. Curve *B* in Fig. 5 shows kw.-output plotted against armature diameter for the four-pole, 1000-volt-per-commutator motor.

Curves for varying track-gage, or peripheral speed, are not shown, as the effect of these factors on the output is clearly displayed in the curves for the 750-volt motor.

Four-Pole, Axle-Mounted Motor, 1500 Volts per Commutator

The proportion of space for the 1500-volt motor as included in L_k will be the same as for the 750- and 1000-volt-per-commutator machine.

The length of coil extension L_e, and gear face L_g will also be the same.

The output constant C, and length of commutator L_c will, however, be different than for either of the lower voltages.

Taking these factors into account, an expression was derived, as in the preceding cases. Curve *C* of Fig. 5, shows relation of kw.-output to armature diameter for a 1500-volt-per-commutator, four-pole motor.

Six-Polf, Axle-Mounted, 750 and 1000 Volts-Per-Commutator Motor

The proportions of space for the six-pole 750- and 1000-volt axle-hung motors are the same as for the

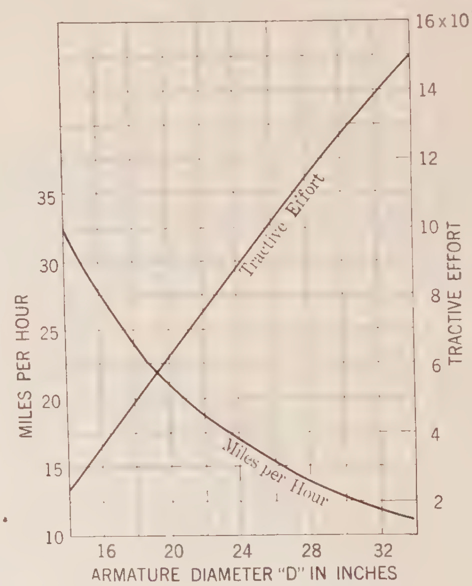


Fig. 12—Axle-Mounted, Four-Pole Motors, Mi. per Hr. and Tractive Effect

four-pole. The length of commutator L_c, and coil extension L_e, will, however, be different, due, in case of commutator length, to the larger number of brush-arms and, in the case of coil extension, to the shorter coil throw.

Curve A of Fig. 13, shows the relations of kw.-output to armature diameter for a six-pole, axle-mounted, 750-volt-per-commutator motor, while curve B, in the same figure, shows a similar relation for the 1000-volt-per-commutator motor.

Frame Mounting—Quill Drive

In the quill drive, the motor is mounted on the spring-born frame of the locomotive, and the main driving axle centered through a hollow quill. The driving gear is mounted on the quill, this quill being held in definite relation to the motor and locomotive frame. The actual drive takes place between the gear and drive-wheel by means of springs which permit the drive-wheel and axle to move in relation to the gear and motor.

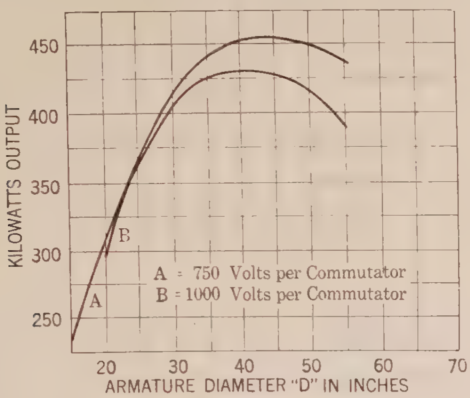


Fig. 13—Axle-Mounted, 3000-Volt, Six-Pole Motors 3500 Ft. per Min. Peripheral Speed, 56.5 In. Track Gage

In general, it is found desirable to have somewhat more clearance between the wheel-flange and end-housing of motor in quill-mounting, than in axle-mounting; otherwise the proportions of space are the same and, therefore, the curves of output will be approximately the same as those for axle-mounting.

The quill drive does, however, permit the use of a twin motor construction and thus, unless limited by the drive, gives twice the power per axle as with an axle-hung motor.

Frame-Mounting Side-Rod or Gear and Side-Rod Drive

In the case of frame-mounted motors, with side rod or gear and side-rod drive, the distance between the side frames of the locomotive L_t, available for the motor, is not a definite quantity, but for the case of inside-hung frames, perhaps 44 in. will be a fair average for the size of locomotives under consideration.

If the motor is made self-contained, so that it may be lifted out of the locomotive frame complete, there will be less room available for active material than if the armature bearings are mounted in the side-frame of the locomotive and end-housings omitted except for comparatively thin protective covers. For the latter case, the constant L_k will contain the following:

1.	Clearance between the frame and commutator V-ring	0.75 in.
2.	Creepage on commutator V-ring	2.50 in.
3.	Commutator groove and clearance between brushes	0.75 in.
4.	Cell extension both ends	2.00 in.
5.	Clearance between coil and frame at rear	1.25 in.
	Total for L_k	7.25 in.

In this case, space need not be allowed for gears and the output equation becomes:

$$\text{kw.} = (L_t - L_c - L_e - L_k)\, D^2\, C\, S \tag{28}$$

From which with the proper substitutions and a peripheral speed of C_s

$$\text{kw.} = \frac{3.82\, C_s\, D\, C\, (L_h - C_c\, D)}{1 + 3.82\, C_s\, C\, C_c\, D} \tag{29}$$

Substituting the proper constants for a 750-volt, four-pole, frame-mounted motor, in equation No. **29**,

$$\text{kw.} = \frac{(37.6\, D - 0.46\, D^2) \log (0.385\, D - 1.31)}{1 + 0.0231\, D \log (0.385\, D - 1.31)} \tag{30}$$

The graph of equation (**30**) is given as curve A in Fig. 18.

In a similar manner, expressions were derived for six, eight-and ten-pole 750-volt motors, and the results shown in curves B, C and D of Fig. 18. Also, expressions for four-and six-pole motors, with 1000-volts per commutator, were derived and the results shown in curves A and B of Fig. 19.

Gearless Motors

The gearless motor may be divided into two classes:

1. Direct axle-mounting
2. Quill-mounting

Direct Axle-Mounting. In this case the armature is pressed directly on the driving axle, and therefore follows the motion of wheels and axle in both a vertical and lateral direction. This, for all practical purposes, necessitates a bi-polar construction with the pole faces

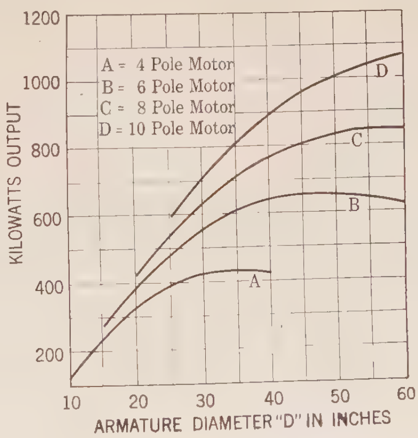


Fig. 18—Frame-Mounted, 3000-Volt Motors, 3500 Ft. per Min. Peripheral Speed, 750 Volts per Commutator

A = Four-Pole Motor
B = Six-Pole Motor
C = Eight-Pole Motor
D = Ten-Pole Motor

eccentric to the armature, thus permitting the movement of the core vertically in relation to the poles.

With this type of motor design, it is desirable, from a mechanical standpoint, to have a comparatively large air-gap, also the pole constant C_p will be relatively small; the latter, taken by itself, would mean a low output constant, but owing to the comparatively low rotational speed and the bi-polar construction, the

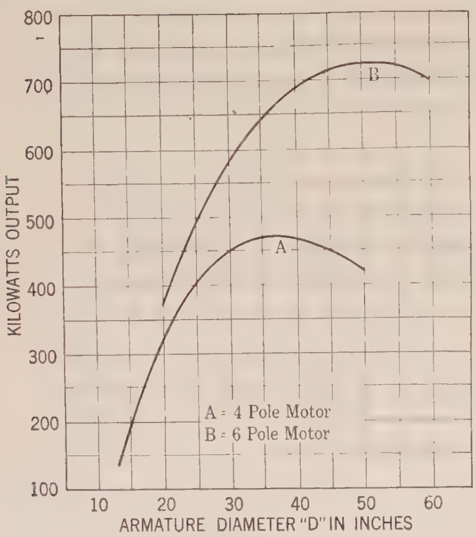


FIG. 19—FRAME-MOUNTED, 3000-VOLT MOTORS, 3500 FT. PER MIN. PERIPHERAL SPEED, 1000 VOLTS PER COMMUTATOR

frequency will, in general, be quite low, and, therefore, the air-gap, teeth, and core-flux density may be high without undue iron loss or heating, thus giving a higher output constant than would otherwise be the case.

It is even more difficult to give an expression for the so-called output constants in terms of the armature diameter for the bi-polar type of construction than for the motor with a larger number of poles, but, by segregating the separate factors which go to make up the output constant, it is believed that no gross error has been introduced.

The same nomenclature will be used for division of space between wheel flanges as was used on the axle-mounted, geared motor, but in this case, the constant L_k will be made up of the following items:

1.	Clearance between wheel and commutator V-ring . .	2.25 in.
2.	Creepage on commutator V-ring	2.50 in.
3.	Commutator groove and clearance between brushes	1.00 in.
4.	Cell extension both ends	2.00 in.
5.	Clearance between wheel and rear of armature	2.25 in.
	Total L_k	10.00 in.

The problem of output will be approached in a somewhat different manner for the bi-polar gearless than for the proceeding type.

It will be assumed that the clearance between armature surface and rail is constant at 7½ in., regardless of armature diameter, thus giving an armature diameter 15 in. less than the diameter of wheel.

At 25 mi. per hr. which is used as a basis of comparison, the peripheral speed of wheel is 2200 ft. per min. If

R = rev. per min. of wheel and armature at 25 mi. per hr.

D_w = Wheel diameter in inches

Then

$$R = \frac{2200 \times 12}{D_w \times \pi} = \frac{8400}{D_w} \tag{31}$$

also

$$R = \frac{C_s \times 12}{(D_w - 15)\,\pi} = \frac{3.82\,C_s}{D_w - 15} \tag{32}$$

where C_s = Peripheral speed of armature in ft. per min. equating (**31**) and (**32**) and solving for C_s

$$C_s = \frac{2200\,(D_w - 15)}{D_w} \tag{33}$$

The construction of the bi-polar, gearless motor does not permit the use of commutating poles and the armature winding may, therefore, be chorded to the point where further chording would give a reduction in counter electromotive force, and increase the speed for a given flux per pole. This coupled with the wide interpolar space, gives a wide commutating zone and permits the use of a wider brush than might otherwise be used. The chording also shortens the armature-winding end-extension.

For the case of 1000-volts-per-commutator, brush

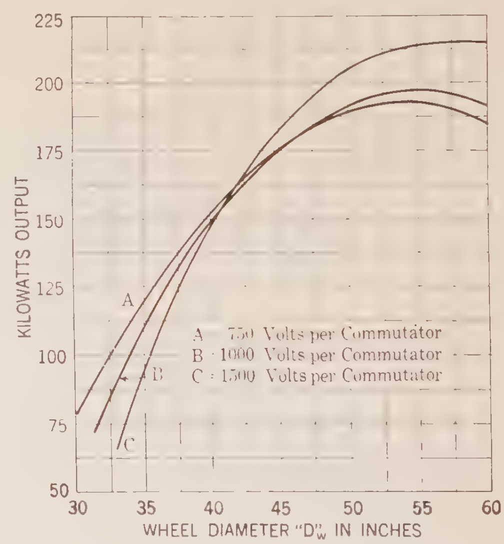


FIG. 20—GEARLESS 3000-VOLT BI-POLAR MOTORS, 25 MI. PER HR. 56.5 IN. TRACK GAGE

width of 0.75 in., 60 amperes per sq. in. in brush, and 90 per cent efficiency at the one-hour rating.

the commutator face = 0.0247 kw.

neck = 0.0035 kw.

or neck + face = L_c = 0.0282 kw. (**34**)

Without giving details of derivation, the following expression for coil extension was used:

$$L_e = 0.6\,(D_w - 15) \qquad (35)$$

also the output constant within the range considered was given the following value

$$C = \log\,(1.45\,D - 13.5)\;3.43 \times 10^{-5} \qquad (36)$$

In order, therefore, to obtain an expression for kw.-output in terms of wheel-diameter for the bi-polar gearless motor equations (**33**) and (**36**) and the following values were substituted in equation (**29**):

$$D = D_w - 15$$
$$L_h = 43.25$$
$$C_e = 0.6$$
$$C_c = 0.0282$$

giving

$$\text{kw.} = \frac{(20.3\,D_w^2 - .173\,D_w^3 - 490\,D_w + 3380)}{D_w + (0.00813\,D_w^2 - 0.244\,D_w + 1.84)}$$

$$\frac{\log\,(1.45\,D_w - 35.3)}{\log\,(1.45\,D_w - 35.3)} \qquad (37)$$

Curve *B* in Fig. 20, is the graph of equation (**37**).

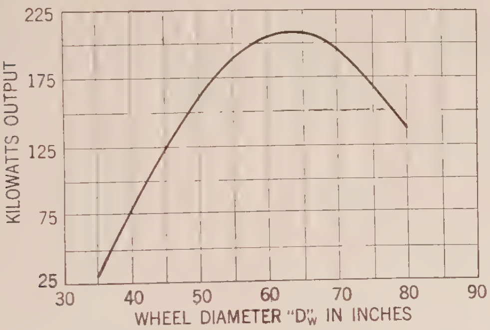


Fig. 21—Gearless 3000-Volt, Four-Pole Quill Motor 25 Mi. per Hr., 1000 Volts per Commutator 56.5 In. Track Gage

If, in place of varying the wheel diameter the peripheral speed or, in other words, the mi. per hr., is taken as the variable and the wheel-diameter held constant at 44 in. the following equation gives the approximate kw.-output in terms of peripheral speed of armature for a 1000-volt bi-polar, gearless motor:

$$\text{kw.} = \frac{0.145\,C_s}{1 + 0.000156\,C_s} \qquad (38)$$

The curve shown in Fig. 22 is the graph of equation (**38**) except that mi. per hr. is used in place of peripheral speed.

Expressions for kw.-output, in terms of wheel-diameter for 750 and 1500 volts per commutator, were derived and the results are shown in curve form as *A* and *C* in Fig. 20.

Gearless Quill-Mounting

With this type of motor, the armature is mounted on a hollow quill which surrounds the driving axle with sufficient clearance between the inside quill wall and axle to allow of maximum movements of wheels and axle in a vertical or horizontal direction. The quill is supported through quill bearings and end-housings by the motor frame, which, in turn, is supported on the spring-borne locomotive frame.

In the case of the gearless quill drive, the constant L_k will be divided as follows:

1.	Wheel flange to commutator V-ring	8.00 in.
2.	Creepage on commutator V-ring	2.50 in.
3.	Cell extension both ends	2.00 in.
4.	Rear end to wheel flange	8.00 in.
	Total L_k	20.50 in.

As was done in the case of the bi-polar, gearless motor, the clearance between the armature surface and rail will be considered constant. This, of course, is not strictly true, as, on this type of motor, room must be allowed for field coil and frame between armature surface and rail, as well as for the proper clearance. However, within the range considered, the assumption will be approximately correct.

This distance between armature surface and rail will be assumed as 11 in., thus giving an armature diameter 22 in. less than the diameter of wheel.

From this point on, the same procedure was followed as for the bi-polar gearless, except for difference in number of poles, output constant, etc.

Fig. 21 shows kw.-output plotted against wheel diameter for a four-pole, 1000-volt-per-commutator gearless quill mounted motor.

1000-Volt Motors

Some explanation may be in order as to why 1000 volts was chosen as an illustration of the use of lower voltage in place of,—for example,—600 or 750 volts.

In general, the designer of d-c.-traction motors is confronted with two difficulties,—not limits, but difficulties; that is, for 1500-volts-per-commutator motors, commutating difficulties are encountered, especially for two-circuit armature windings. On the other hand for 600-volts-per-commutator motors, the size of commutator becomes unduly large for a given number of poles. As a happy medium, therefore, 1000 volts was chosen.

It is realized, of course, that this is not a standard line voltage, but in making this choice, a higher line voltage was presupposed, either a-c. or d-c., with some method of conversion to a lower voltage for use on the traction motors.

For the purpose of this paper, the following classification has been chosen for the 1000-volt motors:

1. Axle-hung Gear Drive
   - *a.* Four-poles
   - *b.* Six-poles
2. Frame-mounted, Quill and Gear Drive
   - *a.* Four-poles
   - Six-poles

3. Frame-mounted, Gear and Side-Rod Drive
   a. Four-pole
   b. Six-pole
   c. Eight-pole
4. Gearless
   a. Two-pole
   b. Four-pole
   c. Six-pole

The analysis of this class of motor was made in

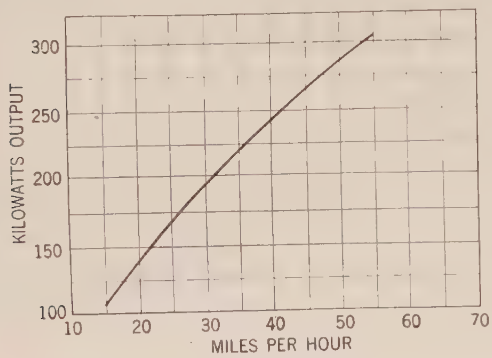


Fig. 22—Gearless 3000-Volt Bi-Polar Motor, 44 In. Wheel Diameter, 56.5 In. Track Gage, 1000 Volts per Commutator

much the same way as for the 3000-volt motor; therefore, the giving of details would be a needless repetition.

Two factors, however, should be mentioned; viz, the better slot-space factor for the 1000-volt motor, due to the use of less insulation, this giving a higher output constant, and the smaller creepage surfaces on the commutator *V*-ring and shorter cell-extension outside of the core.

For the case of 1000-volt motors, therefore, the out-

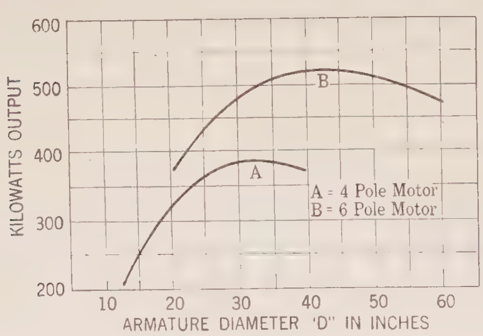


Fig. 23—Axle-Mounted 1000-Volt Motors, 3500 Ft. per Min. Peripheral Speed, 56.5 In. Track Gage

put-constant was expressed imperically as follows:

$$C = \log (0.32D + 0.2)\; 8.2 \times 10^{-5}$$

and L_k was made up of the same items as given for the 3000-volt, axle-mounted motor, except that the creepage on the *V*-ring and the cell-extension for both ends were each given a value of one inch, giving for the total 12.75 in.

It will be noted that this value of L_k is 2.50 in. less for this voltage motor than for the 3000-volt, axle-mounted geared motor. This same reduction holds true also for the frame-mounted and gearless motors of this type.

Expressions were derived for 1 *a*, and 1 *b*, 3 *a* and 3 *b*, and 4 *a* of the classification table. Curves *a* and

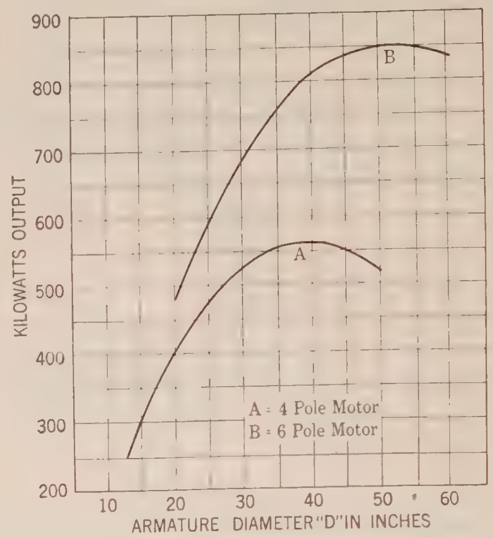


Fig. 24—Frame-Hung, 1000-Volt Motors, 3500 Ft. per Min. Peripheral Speed

b of Fig. 23 give kw-output in terms of armature diameter for a 1000-volt, axle-mounted geared motor, four-pole and six-pole respectively.

Curves *a* and *b* of Fig. 24 give kw-output in terms

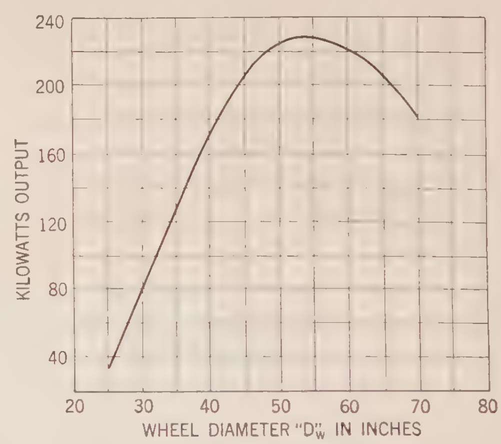


Fig. 25—Gearless 1000-Volt Bi-Polar Motor, 25 Mi. per Hr., 56.5 In. Track Gage

of armature diameter for a 1000-volt frame-mounted motor, four-pole and six-pole, respectively.

Curve of Fig. 25 gives kw.-output in terms of wheel diameter for a 1000-volt, bi-polar, gearless motor.

Discussion of Curves and Conclusions

It will be noted that in the foregoing no mention has been made of commutation limits. This will actually prove the practical limiting factor in some cases, but in general it may be met by refinements in design. However, the flashing and commutation characteristics of a d-c. motor limit the number of poles which

may be used for a given armature diameter, and it is largely for this reason that the classification given at the opening of this paper was employed.

The paper is not intended to include a discussion of types of locomotive-drive, but the application is so intimately allied with this much discussed problem that it must be touched on, at least incidentally.

Reverting now to Fig. 5 which shows output in kw. for four-pole 750-, 1000- and 1500-volt motors, plotted against armature diameter, it will be noted that for the smaller diameters, the lower voltage make the better showing. However, as the diameters increase the higher voltage approaches and finally crosses the lower voltage curve. All three voltages reach a maximum output at between 32-in. and 36-in. diameter with very little gain after 32-in. diameter.

It is evident, therefore, that there is a real limit to the amount of power which may be placed between the wheels with an axle-mounting, regardless of wheel size. Fortunately, this limit is sufficiently high to permit of a fairly heavy axle loading with speeds between 15 and 20 mi. per hr. This, coupled with the simplicity of drive and ruggedness of motor construction, place the combination well towards the front as a solution of the direct-current heavy-traction problem.

The curves of Fig. 13 for six-pole, axle-mounted motors as compared with those of Fig. 5, show the advantages of a larger number of poles for a given armature diameter and also show that it should be possible to place more power between the wheels with the larger number of poles. The point of maximum output, however, is not reached in this case under 40-in. armature diameter.

The curves of Fig. 18 show the advantage of a larger number of poles in obtaining large output when faced by space limitations, and also show that the amount of power which the motor designer is able to produce is practically unlimited in the case of frame-mounted motors.

The output for the bi-polar, gearless motor is shown in Figs. 20 and 22, and is also limited. This limit may, however, be determined more by the dead-weight per axle than by maximum output limit. It will be noted from Fig. 22 that this type of motor finds, perhaps, its best application in high-speed service.

The curves of Fig. 23 for the 1000-volt motor should be compared with similar curves of Figs. 5 and 13 for the 3000-volt motor. The gain in maximum output is quite pronounced, approximately 20 per cent for the four-pole and 15 per cent for the six-pole motor. The same advantage is also shown when comparing curves of Fig. 24 with those of Fig. 19 for frame-mounted motors.

The curve of Fig. 25 for a 1000-volt, bi-polar gearless motor as compared with Curve *B* of Fig. 20 also shows the advantage of the lower voltage motor in so far as output is concerned.

It would seem, therefore, that in so far, at least, as the driving motors are concerned, a very decided advantage may be gained by the use of lower voltage,—say around 1000 volts. The method or methods of obtaining this voltage is beyond the scope of this paper, but we believe sufficient evidence has been presented to show that the direct-current motor designer has something to offer in return for the lower applied voltage to the motor.

In conclusion it may be said that d-c. motors may be built for any type of locomotive drive. The qualifications of the more common types are summed up, as follows:

1. Axle-mounted d-c.-motors may be built which have sufficient power to permit fairly heavy axle loadings, as shown by the curves.
2. Quill drive d-c.-motors may be built, of which the power-per-axle will probably be limited by the method of transmitting power to the wheels rather than by the motors, themselves.
3. D-c.-motors for for side-rod or gear and side-rod drive may be built with practically any desired power.
4. D-c.-gearless motors may be built which have sufficient power for comparatively light axle loadings, this light axle loading necessitating a larger number of axles for a given locomotive rating than would otherwise be used.
5. A lower voltage motor has a definite advantage in possibilities of greater output for a given armature diameter.

GROWTH OF DEMAND FOR ELECTRICAL EQUIPMENT

Prior to 1910 the electric light and power industry in China was in an embryo stage. Practically all the plants which were supplied were of European manufacture and few, if any, turbo-generators had been considered. In 1910 an American company sold a 350-kw. turbo-generator to the Mukden Electric Light Co., the first to be supplied to China. Later, in the same year, an order was secured for a similar machine of 500-kw. capacity for the Changshun Electric Light Co. At the time of placing these orders they were considered revolutionary, as practically all previous plants installed had been driven by reciprocating engines.

The greatest factor in the increase of electrical power plants has been the growing industrial enterprises in China, particularly for modern industrial plants. A very large part of the output of the Shanghai Municipal Council electrical undertaking is used by local manufacturing concerns. In other sections industrial enterprises have been responsible for the installation of power plants of their own, varying in capacity from 500 to 3000 or 4000 kw.

And simultaneous with the demand for industrial machinery, came the demand for electric lighting for cities, large and small. While the manufacturing industries were confined to districts surrounding the large open ports, lighting installations spread quickly over all parts of China from north to south, with the result that electric lighting plants are now to be found in cities many days' journey from the nearest railways and waterways.

Design of Non-Distorting Power Amplifiers

BY E. W. KELLOGG[1]

Associate, A. I. E. E.

Synopsis.—*The paper deals with the problem of obtaining the maximum output possible from a given amplifier tube, while keeping the distortion down to a negligible amount. A tube can be rated for this purpose in terms of the watts output obtainable, when a sine wave voltage of as great an amplitude as can be advantageously utilized, is applied to the grid. This maximum sine wave output is very much less than the rating of the same tube for oscillator purposes. Starting with a set of static characteristics for a given tube, the dynamic characteristics for any resistance load is readily plotted, and the power output and distortion can be read from the dynamic characteristic. A simple rule has been given by Mr. W. J. Brown for determining the best conditions of load resistance and grid bias for a given plate supply voltage. The best load resistance is shown to be twice the internal plate resistance of the tube. If the supply voltage exceeds a certain value, the application of the rules just mentioned would lead to excessive heating of the anode, and therefore a different procedure is followed, calling for greater grid bias and higher load resistance. There is an advantage in using low impedance tubes. The balanced or push-pull circuit, while reducing distortion, will not make up for failure to operate the tubes under proper conditions, nor will it greatly increase the permissible output per tube. The dynamic characteristic for a reactive load is not readily plotted, but for design purposes it is sufficient to determine the best operating conditions for a resistance load, and then make the impedance of the reactive load high enough to keep the plate current variations within the same limits as for the resistance load. An important application of the principles outlined here, is the design of radio telephone transmitters where serious distortion results from overworking the modulator tubes. For moderately deep modulation there should be from two to four modulating tubes for each oscillator tube. Certain details of design are discussed in the closing paragraphs.*

Problem Encountered in Power Amplifiers

In the design of an amplifier whose function is to bring voice or radio signals from bare audibility to comfortable head-phone intensity, the problem of distortion due to curvature of the tube characteristics is hardly a factor, or at least presents no difficulties. The principal concern of the designer is to obtain a large ratio of amplification per stage, and to avoid serious inequalities in the amplification for different frequencies within the required range. When we design an amplifier to operate a loud speaker or to modulate a radio transmitting set the problem takes on an entirely different aspect. Amplifiers the design of which is concerned chiefly with the amount of power obtainable from the final stage, are of the class which we are here designating as "power amplifiers."

Sine Wave Ratings

The relative power obtainable from various vacuum tubes may be estimated in terms of their power outputs of sine-wave alternating current, a sine-wave alternating voltage being impressed on the grid in each case. The magnitude of the grid voltage required is usually of secondary consideration, since it represents no power consumption and is a small factor in determining the total size and cost of the amplifier.

Comparison with Oscillator Ratings

Power tubes as sold are usually given a rating in watts. This rating represents the high frequency output when the tube is used as an oscillator. The power available from the same tube with the same plate voltage is much less when distortionless amplification is required, for the reason that in the amplifier, operation must be confined to a portion of the characteristic which is straight, or substantially so, while the oscillator has no such limitation. Thus we find that a tube rated at 250 watts output as an oscillator can supply only about 22 watts of sine-wave output as a straight-line amplifier at the same average plate voltage. Fig. 1 shows the relative working range on a small scale. It will be noticed that the amplifier range is shown as limited to negative-grid voltages. If the grid is allowed to become sufficiently positive (with respect to the negative end of the filament) to take an appreciable electron current, it imposes an irregular load on the preceding tube which causes wave form distortion. In other

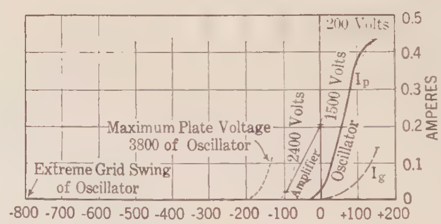


Fig. 1—Comparison of Working Range of Oscillator and Amplifier

words, it is necessary not only that the plate-current vs. grid-voltage characteristic be a straight line but the grid current vs. grid voltage characteristic must be straight over the working range as well, and the only straight part of any considerable length is where the grid current is zero.

Necessary Measurements

We can calculate the performance of a tube from its "static characteristics," or the voltage-current relations obtained point by point by means of meters. The characteristics required are a set of curves showing the plate current as a function of grid voltage, each curve corresponding to a designated plate voltage. Fig. 2

1. Research Laboratory, General Electric Co., Schenectady, N. Y.

Abridgement of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-13, 1925. Complete copies available upon application at headquarters.

shows the static characteristics for a certain tube having an oscillator rating of 250 watts. The series of plate voltages chosen should preferably be at uniform intervals, and sufficiently near each other to give ten or more curves, ranging from about one-fourth to double the average voltage at which the plate is to be worked.

Dynamic Characteristic

The simplest circuit to analyze is that shown in Fig. 3, in which the alternating current output of the tube is used up in the resistance through which the direct

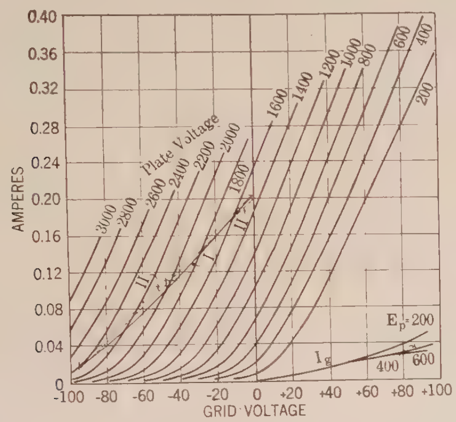


Fig. 2—Static and Dynamic Characteristics of Three Electrode Tube

current is fed to the plate. While this does not appear to represent the conditions of a practical circuit, we shall find that the conclusions reached in this case are applicable to the commonly employed circuits shown in Figs. 9 and 10. The only essential difference is that in the latter circuits the average plate voltage is practically the same as the supplied voltage.

For the present, considering that the circuit is as shown in Fig. 3 let us find from Fig. 2 the operating characteristic or "dynamic characteristic" for some

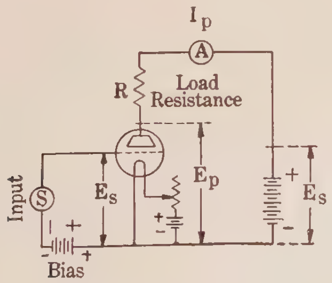


Fig. 3—Simple Circuit for Determining Rating of Amplifier Tubes

assumed value of external resistance R, and supply voltage E_s; for example, $R = 5000$ ohms and $E_s = 2500$. If the grid voltage is given such a value that the plate current is 0.1 ampere, the voltage at the plate will be $2500 - 0.1 \times 5000 = 2000$. Similarly, 2200 volts at the plate corresponds to

$$\frac{E_s - E_p}{R} = \frac{2500 - 2200}{5000} = 0.06 \text{ amperes},$$

2400 volts corresponds to 0.02 amperes and 1800 volts to

$$\frac{700}{5000} = 0.140 \text{ amperes.}$$

Points are plotted for these values of current on the corresponding voltage curves, and a curve through the points as shown in Fig. 2, is the dynamic characteristic for the conditions assumed. It will be noticed that while the dynamic characteristic or working curve is straighter than the curves for constant plate voltage, it begins to bend decidedly at low current values, where the other curves turn most sharply. Thus, to keep the wave form distortion within proper limits, the minimum current must not fall below a certain value. In the present case we will take 0.02 amperes as the minimum current. This corresponds to 2400 volts on the plate and -96 volts on the grid. The other end of the working range is zero grid volts, which, from the curve, is seen to correspond to 1500 volts at the plate and 0.2 amperes. A current varying from 0.02 to 0.2 ampere is equivalent to a direct current of 0.11 amperes, with a superimposed alternating current of 0.09 ampere maximum or $\frac{0.09}{\sqrt{2}}$ ampere effective value. Similarly the voltage varying from 1500 to 2400 is equivalent to a direct voltage of $\frac{1500 + 2400}{2} = 1950$, and an alternating voltage of $\frac{2400 - 1500}{2} = 450$ volts maximum or $\frac{450}{\sqrt{2}}$ volts effective. And the a-c. power consumed in the resistance R is $\frac{0.09}{\sqrt{2}}$ by $\frac{450}{\sqrt{2}} = \frac{0.09 \times 450}{2}$ $= 20.25$ watts. The calculation of power may be abbreviated to

$$\frac{(E_{max} - E_{min})\ (I_{max} - I_{min})}{8}$$

$$= \frac{(2400 - 1500)\ (0.2 - 0.02)}{8} = 20.25$$

Estimate of Distortion

In calculating the power, no allowance has been made for possible errors introduced by the fact that the characteristic is not truly a straight line. Fig. 4, Curve I, shows the current wave resulting from impressing a sine wave voltage on the grid, varying from 0 to -96 volts, or in other words, biasing the grid -48 volts and swinging its potential 48 sine ωt. volts. If we draw a straight line II, on Fig. 2, falling as much below Curve I at the ends as it is above it at the middle, and draw the corresponding wave form on Fig. 4, we have a true

sine wave II. The difference between the two curves is almost totally a double frequency component with an amplitude 0.056 of the fundamental. Thus Curve II is the fundamental component in Curve I, and its amplitude is 0.09 amperes, or just what was assumed in calculating the power. In general, where the curvature is all in one direction as is true in nearly all cases in the present problem, the wave-form distortion consists principally in the production of even harmonics, and if only even harmonics are present, the difference between the maximum and minimum current is twice the amplitude of the fundamental. In addition to the 20.25 watts of fundamental-frequency power supplied by the tube to the resistance R, there is a small amount, 0.0006 watts, of higher frequencies.

If the working characteristic, Curve I, Fig. 2, has a practically uniform rate of change of slope, or, in other words, if it can be represented by a piece of a parabola, the only harmonic produced is the second or double frequency, and its amplitude is given by the amount by which the Curve I falls below the straight line II, at the center and rises above it at the ends. For simplicity, it seems desirable to compare curvatures on the

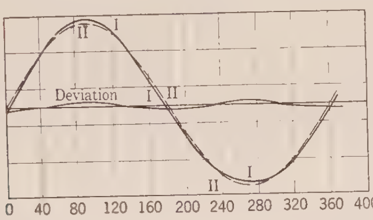


FIG. 4—OUTPUT CURRENT WAVE COMPARED WITH TRUE SINE WAVE

basis of the maximum deviation of the working curve from a straight line, and since a very close approximation to the actual curve can usually be made by a section of parabola, this deviation may be expressed as the percentage of second harmonic produced, taking the amplitude of the fundamental wave as 100 per cent. In Fig. 2, Cuve I is 0.005 amperes below Curve II at the center, and the same amount above it at the ends, so that the second harmonic has an amplitude of 0.005 amperes, as against 0.09 amperes for the fundamental.

The ratio is $\frac{0.005}{0.09} = 0.056$ or 5.6 per cent. If the straight line were drawn between the ends of Curve I, it would be 0.01 amperes above Curve I at the middle, and the ratio of this to the total current range is $\frac{0.01}{0.18}$ or again 5.6 per cent. It is unnecessary to draw the straight line. The ratio of second harmonic to the fundamental is

$$\frac{\frac{1}{2}\,(I_{max} + I_{min}) - I_0}{I_{max} - I_{min}} = \frac{0.11 - 0.10}{0.18} = 0.056$$

in which I_0 is the plate current corresponding to the mean-grid voltage, which is $-\frac{0 + 96}{2} = 48$ volts in this case.

It is sometimes more convenient to find the deviation of the curve from the straight line connecting its ends, by a horizontal instead of a vertical measurement at the middle. This horizontal deviation (expressed in grid volts) divided by the total grid swing should give the same result as the vertical deviation divided by the total current swing, provided the curve is parallel to the straight line at the middle. In this case the middle value for plate current is 0.11 amperes which, on Curve I, corresponds to $-$ 43 volts grid, and the relative magnitude of the second harmonic by the grid voltage measurement is $\frac{48 - 43}{96} = 0.052$. The discrepancy is within the limits of accuracy in reading the curves.

If the wave form distortion just calculated is considered more than allowable, it may be reduced by shortening the range, especially by raising the minimum plate current. For example, if the grid voltage varies only between zero and $-$ 88 volts the other conditions remaining the same, we shall have

E_g	E_p	I_p	
0	1500	0.2	I_{max}
-88	2350	0.03	I_{min}
-40	1925	0.115	$\frac{1}{2}(I_{max} + I_{min})$
-44	1962	0.1075	

$$\text{Power} = \tfrac{1}{8}\,(850 \times 0.17) = 18 \text{ watts}$$

Second harmonic ratio $= \frac{0.0075}{0.17} = 0.044$ by current values, or

$$\frac{4}{88} = 0.0455 \text{ by grid}$$

voltages.

EFFECT OF HIGHER LOAD RESISTANCE

Let us next try a higher resistance load, 10,000 ohms, raising the supply voltage to 2800, so that with 0.08 ampere flowing, the plate voltage will be 2000. This gives a point on Curve I of Fig. 5, where the characteristics of the same tube have been redrawn. A change of 200 volts at the plate corresponds to a current difference of $\frac{200}{10{,}000} = 0.02$ amperes. Starting with the 2000 volt and 0.08 ampere point we may plot the new dynamic characteristic by marking a series of points on the successive voltage curves, each point differing from the preceding one by 0.02 amperes. Again taking 0.02 amperes as the minimum plate current, we find we can swing the grid between zero and $-$ 105 volts, giving

E_g	E_p	I_p	
0	1280	0.152	I_{max}
−105	2600	0.02	I_{min}
− 49	1940	0.086	$\frac{1}{2}(I_{max} + I_{min})$
− 52.5	1980	0.082	I_o (for mean E_g)

Total current range 0.132 amperes
Total voltage range 1320 volts.
Power $\frac{1}{8}$ (.132 × 1320) = 21.8 watts

Second harmonic ratio $\dfrac{0.086 - 0.082}{0.132} = 0.03$ by current values

$$\frac{52.5 - 49}{105} = 0.033$$ by grid voltage

The above figures are comparable with those taken from Curve I Fig. 2, on the basis of substantially the

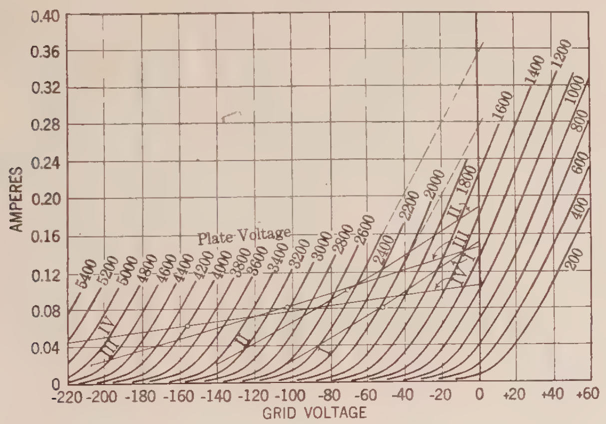


Fig. 5—Dynamic Characteristics with Various Values of Load Resistance

same plate voltage when the grid is at its mean potential. Two results of going to a higher load resistance should be noted; there is more power output, and, for the same value of minimum plate current, the wave form distortion is less. The internal resistance of the tube is about 5000 ohms, and that more power should be delivered to a 10,000-ohm load than to a 5000-ohm load may seem at first surprising to those who are accustomed to think in terms of impedance fit. With a fixed grid swing the 5000-ohm load would receive the greater power, but with the high impedance load, the grid may be swung farther before distortion becomes serious. The common practise of applying a voltage to the grid (from an oscillator, microphone and amplifier, or radio receiving set)—and then varying the load impedance by trying various transformer ratios and selecting the tap which gives the loudest response,—is misleading. A tap which gives weaker response than the maximum may, when the input is readjusted, enable the amplifier to put out more power without distortion.

Best Conditions when Voltage is Limited

Mr. W. J. Brown[1] has given a simple rule for selecting the best load impedance and working range for the case where the mean voltage on the plate is limited to a certain value, and also a proof that the maximum power will be received by a load resistance equal to twice the internal resistance of the tube. In Fig. 6, $F\,D$ is the minimum value of plate current, below which the curvature becomes excessive; $A\,B$ is the plate current curve for a constant plate voltage equal to the mean plate voltage assumed in the problem, and $E\,C$ is the working curve. The constant voltage, curve $G\,C$, corresponds to the minimum voltage, and $E\,H$ to the maximum. The voltage amplitude is $r\,(B\,C)$ where r is the internal tube resistance, and the root-mean-square alternating voltage is $\frac{1}{\sqrt{2}}\,r\,(B\,C)$. The measurement $C\,D$ is equal to twice the current amplitudes, or the root-mean-square alternating current is $\frac{1}{2\sqrt{2}}\,(C\,D)$. The product of the r. m. s. voltage and current, or the power, is equal to

$$\frac{1}{\sqrt{2}}\,r\,(B\,C)\,\frac{1}{2\sqrt{2}}\,(C\,D) = \frac{r}{4}\,(B\,C)\,(CD)$$

Since the measurement $B\,D$ is fixed, the product $(B\,C)\,(C\,D)$ is a maximum when $B\,C = C\,D$ or C is located half way between D and B. The value of the

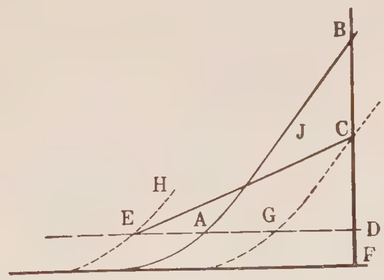


Fig. 6—Diagram Illustrating Method of Determining Best Operating Conditions

external resistance is equal to $\dfrac{\text{voltage amplitude}}{\text{current amplitude}}$

$$= \frac{r\,(B\,C)}{\frac{1}{2}\,(C\,D)} = 2\,r \text{ when } B\,C = C\,D.$$

The location of the point C and the value of the load resistance determine the working characteristic $E\,C$, and its intersection with $A\,B$ determines the proper value of grid bias.

In the foregoing it is assumed that r is constant, but since this is not the case the result is only an approximation. For larger currents r is less than for small

1. Discussion, Symposium on Loud Speakers, *Proceedings of London Physical Society*, Vol. 36, Part 3. April 1, 1924.

currents, and the value of r in the relation,—voltage amplitude $= r\ (B\ C)$, changes with the location of C. With r a function of the position of C, the condition for maximum product $r\ (B\ C) \times (C\ D)$ is no longer that $B\ C$ shall equal $C\ D$. The shape of the characteristics above the level of the point C can have no bearing on the operation. It would appear logical to use a value of r corresponding to currents between $F\ D$ and $F\ C$ and to locate the point B as if the same value of r held for the higher currents. This means simply to draw the upper part of the line $A\ B$ straight, maintaining a slope equal to that in the working range $A\ J$. This point is brought out not because the error in the method described by Mr. Brown would, in general, be serious, but because in many cases the upper parts of the curves $A\ B$ are more difficult to obtain experimentally or data to plot them may be lacking. As in many other problems involving maxima, precision is not required here, the output remaining nearly the same through a wide range in load resistance.

Limitation Set by Anode Loss

We have so far considered the case where the mean plate voltage is limited, for example by the available supply, but where no other limitation is imposed. If the supply voltage can be raised sufficiently to enable the tube to put out all the power of which it is capable the limit of output may be set either by the power which can safely be dissipated from the plate, or by a combination of plate dissipation and insulation. For voltages below a certain value the rule illustrated in Fig. 6 is applicable. Applying this rule, the output goes up very fast with increase of voltage, and the average power supplied to the plate also increases rapidly. For example, Curve I of Fig. 5 is for a mean-plate voltage of 2000 and gives 21.8 watts output and 162 watts, plate loss. Curve II is for 2400 volts and gives 40.8 watts output and 250 watts plate loss. This is the maximum plate loss which we may safely allow for the tube in question. Up to this point the mean plate current has been increasing with increase of voltage. For higher voltages the current must be limited to

$$\frac{\text{Permissible plate loss}}{\text{Mean plate voltage}}$$

The mean plate voltage and plate current determine the grid bias. Since the grid voltage may swing to zero in the positive direction, the extreme negative swing will be twice the bias. The minimum value of plate current and the extreme negative grid potential fix the lower end of the working characteristic and the maximum plate voltage. Thus we have the voltage amplitude and the current amplitude, from which we find the load resistance and the power output. Referring again to Fig. 5, if the mean plate voltage is 3000, the mean current is limited to $\dfrac{250 \text{ watts}}{3000 \text{ volts}} = 0.0833$ amperes. On the 3000 volt curve we find that the grid bias corresponding to 0.0833 amperes is -103 volts. The grid may then swing between zero and -206 volts. The plate voltage corresponding to 0.02 amperes, assumed minimum current, and 206 grid volts is 4700. Then the voltage amplitude is $4700 - 3000 = 1700$, the current amplitude $0.0833 - 0.02 = 0.0633$, the load resistance $\dfrac{1700}{0.0633} = 26{,}800$ and the power output $\dfrac{1700 \times 0.0633}{2} = 54$ watts. With the load resistance known the working curve may be drawn. If its intersection with the zero grid volts axis shows that the current and voltage swing during this half cycle is greater than during the other, there will be a correction to the power calculation. In this case the maximum current is 0.148 amperes and the minimum voltage is 1250. The revised power calculation is then $\dfrac{(4700 - 1250)\ (0.148 - 0.02)}{8} = 55$. If the curvature is small as in this case it is hardly necessary to draw the curve, the first calculation being sufficiently close.

If experimental characteristics at the extreme high voltages are not available, substantially the same result may be obtained if the curvature is slight, by locating the upper end of the working characteristic, which will be on the zero grid volts line, and with a plate current value as much above the average, as the minimum is below. If there is considerable curvature it is better to follow the first method, drawing in additional constant voltage curves by extrapolation if necessary. Fortunately for the ease of extrapolation the constant voltage characteristics are substantially alike in shape, and each is displaced horizontally from the next by the voltage interval divided by the amplification constant of the tube.

That the method just described will give the greatest possible power output for the voltage and mean plate current assumed, may be seen from the following. In swinging the grid from zero to twice the bias, we are using the largest grid swing allowable, increasing the bias without raising the plate voltage would give only a small increase in grid range, but a large reduction in current amplitude. Any lower load resistance would cause the lower end of the working curve to fall below the permitted minimum plate current, and therefore give distortion. Any higher load resistance with the same grid swing would decrease output, because we are already using a resistance much higher than the internal resistance of the tube, and it is a general principle that with a given grid swing, the more nearly the load resistance can be made to approach the tube resistance the greater will be the tube output.

The following table shows how the output of the tube with characteristics given in Fig. 5, varies with the

voltage of the plate supply. The voltage E_0 given in the first column is the plate voltage when the grid is at its bias potential, and I_0 is the corresponding plate current.

Plate Volts E_0	Plate Amperes I_0	Grid Bias	Plate Loss	Output Amperes Max. A. C.	Output Volts Max. A. C.	Output Watts	Load Resist	Second Harmonic Ratio
1980	0.082	−52.5	162	0.066	660	21.8	10,000	0.03
2460	0.10	− 71	246	0.085	960	40.7	11,250	0.03
3000	0.0833	−103	250	0.064	1725	55	26,800	0.0052
4000	0.0625	−157	250	0.0425	2970	63	70,000	
5000	0.05	−210	250	0.03	4120	62	137,000	

Since the tube is not designed to withstand more than approximately 2500 volts, the maximum output which can be realized is 41 watts. The purpose of carrying the calculations to higher voltages is merely to illustrate the method of determining load impedance and output when plate loss rather than plate voltage is the limiting factor, and to bring out certain relations. In the above table the minimum current has been taken throughout as 0.02 amperes, although in view of the fact that distortion is less with the high resistance loads, the lower limit of current might properly have been reduced. Had this been done the maximum output would have occurred at a still higher voltage. If we permitted the minimum current to go to zero it would have appeared that the output increased indefinitely with increase of voltage. This is because the voltage also cannot go to zero. The power output of the tube is $\frac{1}{2}(I_0 - I_{min})(E_0 - E_{min})$ which becomes $\frac{1}{2} I_0 (E_0 - E_{min}) = \frac{1}{2} I_0 E_0 - \frac{1}{2} I_0 E_{min}$ if I_{min} is zero. As the voltage is increased, the supplied watts $E_0 I_0$ being maintained constant, I_0 becomes less and also E_{min}, so that the output approaches $\frac{1}{2} I_0 E_0$.

Limiting Value of Output

If the tube impedance is lowered by using coarser grid mesh or closer electrode spacings, E_0 can be lowered and a greater output obtained. If we imagine a tube of such low impedance that the voltage could go to zero, as well as the current, the output would be $\frac{1}{2} E_0 I_0$, or one-half the permissible plate loss; and if the latter is kept constant, the output would be independent of the voltage chosen. In practical cases, it appears in general that, for a given value of plate loss, the lower the tube impedance and the higher the supplied voltage, the greater will be the output, and for most efficient use, a power amplifier tube should be worked at the highest voltage compatible with good life.

Output Subtracts from Plate Loss

The average power $E_0 I_0$, supplied to a straight line amplifier tube, is the same whether an alternating voltage is impressed on the grid, or the grid potential remains stationary at the bias value. When the tube is operating into a resistance load, the plate loss is reduced by the amount of the useful output. However, this does not make it permissible to make $E_0 I_0$ greater than the allowable plate loss, for amplifiers do not operate with any fixed grid swing; and even if an amplifier should be used for constant tone production the alternating voltage might go off at any time. Nor should it be inferred that in all amplifiers the plate loss will go down when an alternating voltage is applied to the grid. If there is much curvature or the swing is excessive, the average current will generally increase, and if the load is of low resistance there will be little power absorbed in the load to offset the increase in the supplied watts. Under such conditions the plate loss may increase when alternating voltage is applied to the grid.

Permissible Distortion

In comparing various tubes for a given purpose or in assigning power ratings to tubes, it would be logical to set a limiting value of distortion. For scientific or measurement work the distortion permitted would depend on the nature of the work. On the other hand for the reproduction of speech or music it does not seem possible to assign any general rule as to how much distortion should be permitted, nor to give any simple criterion for setting a limit. There is good reason to believe that the response of the ear is not linear, or, in other words, that harmonics are produced in the ear itself[2]. This being the case, the ear would not be critical toward the production of overtones in the amplifiers. On the other hand, if the working characteristic is fairly straight over a certain range and then turns quite sharply, an impairment of quality is quickly noticed if the grid swing exceeds that which corresponds to the straight part of the characteristic. It would appear that much greater deviation from a straight line can be allowed if the curvature is practically uniform, than if the characteristic turns abruptly. While it does not seem possible to set a limit to distortion, applicable to all tubes, the practical limit in a particular case does not seem difficult to decide upon. For example, in the case of the tube whose characteristics are shown in Fig. 5; if we assume E_0 to be 2500 volts and the plate loss not to exceed 250 watts, we can assign various values to the minimum current and find the maximum power obtainable for each case. A low minimum current means a considerable curvature allowed, but per-

2. "Sensation of Tone" by H. L. F. Helmholtz (Edition of 1877), Chapter VII. Quantitative measurements supporting this theory are given by R. L. Wegel and C. E. Lane, *Physical Rev.*, Feb. 1923. "Auditory Masking of One Pure Tone by Another."

mits more power to be obtained. Fig. 7 shows the power output and the distortion as functions of I_{min}. It will be noticed that below about 0.02 amperes, the gain in output is slow and the increase in distortion is rapid. Analysis of a number of practical tubes indicates that it is rarely necessary to permit more than about 5 per cent distortion in order to realize about all the useful output of which the tube is capable.

Push Pull Circuit

In this connection, the question naturally arises whether the working range can be increased by use of

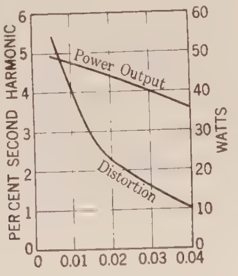


Fig. 7—Relation Between Distortion and Minimum Current

a "push-pull" circuit, like that shown in Fig. 8. Such a connection balances out the even harmonics if the tube characteristics are alike, and is, therefore, a possible means of reducing distortion. The gain in output per tube, however, is small. Referring to Fig. 5, Curve II, we see that, for the range shown the curvature is very slight, but we cannot extend the curve on the lower end without its turning horizontal, nor on the upper end without driving the grid positive. Trying to drive the grid positive causes a distortion of the grid voltage wave

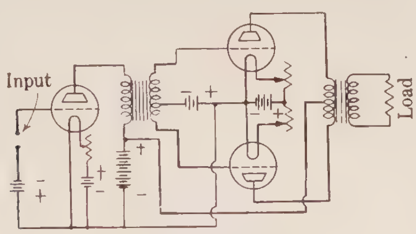


Fig. 8—Balanced or Push-Pull Amplifier Circuit

which has the same effect on the plate current as if the grid voltage wave were not affected, but the working characteristic turned toward the horizontal to the right of the zero-grid-voltage point. A working characteristic which bends toward the horizontal at both ends, or in other words, has a reversed curvature, causes odd harmonics in the output current wave, and the balanced, or push-pull circuit, does not neutralize odd harmonics. While the push-pull circuit does not make it permissible to increase the working range of the tubes appreciably, there are cases in which it is advantageous. For some scientific work, it is important to reduce all distortion to the minimum, and if the tubes are worked over a very moderate range so that only the double frequency harmonics are produced, the balanced circuit can be made to practically eliminate the distortion. It possesses a practical advantage in that the direct currents in both halves of the output transformer winding, balance each other magnetically, thus reducing the tendency to saturate the core, and making a lighter, smaller design of transformer possible. As against these advantages, the push-pull circuit calls for an interstage transformer which introduces some distortion.

Load Circuits

Figs. 9 and 10 show connections frequently used for the output of power amplifiers. In Fig. 9, the choke

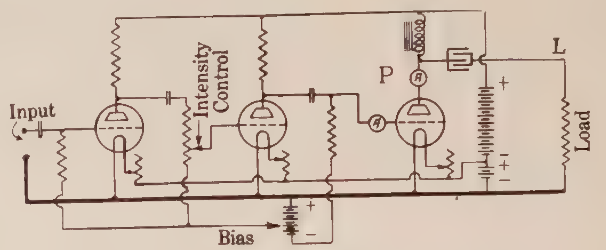


Fig. 9—Resistance Capacity Coupled Amplifier with Choke Coil-Condenser Feed to Load

coil must have a high reactance compared with the tube and load resistance, and the stopping condenser must have a low reactance compared with the load resistance, for all frequencies in the working range. Otherwise, distortion will result, the low frequency currents being partially suppressed either by excessive reactance in the condenser, or too much leakage through the choke. With a properly designed circuit, we may think of the choke as maintaining a constant direct current equal to the average plate current, I_0, while the condenser offers a practically constant counter-electromotive force equal to the average plate voltage E_0. Now, suppose that the plate current

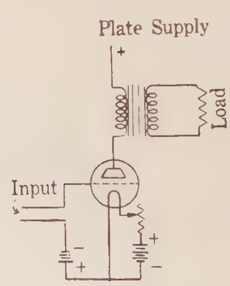


Fig. 10—Transformer Coupled Load

changes momentarily to $I_0 - i$. Since the current through the choke remains constant, the difference or i amperes must flow through the load. The potential at L then becomes $+ i R$ which, added to the strain E_0 on the condenser, brings the potential at P to $E_0 + i R$. Similarly, when the plate current is $I_0 + i$ the load current is reversed, the potential at L is $- i R$ and at P is $E_0 - i R$. It will be recognized that

from the standpoint of the tube, this condition duplicates that illustrated in Fig. 3, the only difference being that in Fig. 3, the supply voltage would have to be $E_0 + I_0 R$ in order to maintain the average voltage E_0 at the plate. The conditions met in the transformer connection of Fig. 10 are similar. An ideal transformer with a resistance R connected to its secondary terminals introduces into the primary circuit, an effective resistance for alternating currents equal to R multiplied by the square of the ratio of primary to secondary turns, but for direct current, it introduces only the ohmic resistance of the primary winding. The practical transformer, if properly designed to avoid distortion, gives a close approximation to the relations just stated. The magnetizing current must be small compared with the load current at the lowest frequencies with which we are concerned, and the series reactance due to leakage flux must be small compared with the load impedance for the highest frequencies considered.

Reactive Loads

We have so far considered only pure resistance loads. The dynamic characteristic for a tube with a reactive load is not readily plotted, but its general form can be shown and the conditions for avoiding distortion as found for the case of resistance load are applicable to the reactive load. If there is reactance in the load, the dynamic characteristic becomes eliptical in form; a true elipse if the constant voltage curves are straight over the range between maximum and minimum current, and a distorted elipse if there is appreciable curvature within this range. It is generally possible to adjust the load impedance to any desired value, either by means of a transformer, or by changing the number of turns in the windings of the instrument which constitutes the load. Such changes do not materially alter the power factor. In fitting a reactive load to the amplifier tube, the procedure recommended is first to determine for the case of a resistance load, the load resistance, plate voltage, grid bias, and grid swing for maximum output; then using the same plate voltage and grid swing, make the load impedance such that the maximum and minimum values of plate current will be the same as in the case of the resistance load. This means making the vector sum of load impedance and tube plate resistance the same for the two cases[3]. If these conditions are complied with, the principal sources of distortion are avoided, namely, swinging the grid positive, and working with too low minimum currents.

Since load impedances are functions of frequency and audio frequency amplifiers must operate properly for a wide range of frequencies, the question arises at what frequency should the load impedance have the value which has been determined as suitable? The only safe rule is to make the calculation for the frequency at which the load impedance is lowest.

3. The alternating current in the plate circuit is equal to

$$\frac{\text{(alternating grid voltage) (amplification constant of tube)}}{\text{(vector sum of load impedance and tube resistance)}}$$

For derivation of this relation see "The Thermonic Vacuum Tube" by H. J. Van der Bijl, pages 157 and 177. See also pages 175 and 176 for discussion of form of dynamic characteristic with reactive load.

Modulation of Radio Transmitters

In a section of the paper which has been omitted on account of lack of space, a method is outlined for calculating the degree of modulation which can be obtained without distortion in a radio telephone transmitter of the type shown in Fig. 11. If the same design of tube is used for modulator as for oscillator it will generally be found that several modulator tubes should be employed for each oscillator tube, in order to take care of the peak voltages without exceeding the straight line range of the modulators. Failure to provide adequate modulator capacity is a frequent cause of distortion in radio transmitters.

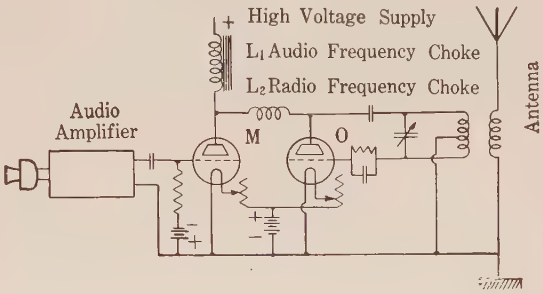


Fig. 11—Radio Telephone Transmitter Showing Method of Modulation

Plate and Grid Ammeters

It is desirable to design the earlier stages of a power amplifier with ample margin so that if any tube is overworked, it will be the power stage. A very satisfactory indicator, to show when the intensity exceeds the straight line capacity of the amplifier, consists in a milliammeter in the grid circuit and a meter in the plate circuit. If the grid swings positive with respect to the filament, the grid meter will "kick" and perhaps the plate meter also, while too great a negative swing will cause a kick on the plate meter. Careful listening will reveal an impairment of quality which disappears as soon as the intensity is reduced to a point where the meters cease to show disturbance. Listening alone is not a satisfactory substitute since the distortion is not so quickly nor surely noticed, particularly in view of fatigue of attention, and if distortion is noticed, its origin might be elsewhere in the system.

Tubes in Multiple

The increased output from a power amplifier obtained by adding power tubes in multiple, is often disappointing, the gain being slow compared with that which can be accomplished with increased voltage or with tubes of higher rating. However, there are cases in which it is desirable to use several tubes in multiple. With the load impedance already several times the tube resist-

ance, which is the proper relation for maximum output, the addition of a second tube in multiple with the first would not give a perceptible increase in output, but if the load impedance is readjusted to half the previous value, twice the power output can be obtained, corresponding to about 40 per cent increase in sound amplitude, which is a noticeable, but not a striking difference.

When several tubes are connected in multiple, they may form an oscillating system and fill the tubes with high frequency oscillations. This is less likely to occur if the connecting wires are made very short, but with high power tubes, it is frequently necessary to employ some means of stopping the parasitic oscillations, such as an individual resistance or choke connected in series close to the grid of each tube. A few turns of wire on a small solid iron core will suffice, since such a choke introduces a high effective resistance at the extremely high frequencies concerned.

Interstage Connections

With a supply of high voltage available, such as is necessary for the power tubes, the design of the preceding amplifier stages is simple. Resistance-capacity coupling can be used with sufficiently high plate resistance to obtain three-fourths or four-fifths of the full amplification of the tube. Under these circumstances, and with high amplification tubes available, there would be little argument for transformer coupling. In designing a resistance-capacity coupled amplifier, the following points must be kept in mind:

1. The reactance of the coupling condenser at the lowest frequency to be passed, must be less than the grid leak resistance.

2. No grid should swing positive with respect to the negative end of the filament, or, in other words, the grid bias must be greater than the extreme grid swing required. This does not apply to detector tubes.

3. If the expected swing in plate potential of any tube is more than about 20 per cent of the average voltage on the plate or if the plate current is very small, the dynamic characteristic should be worked out to make sure of constant proportionality between plate and grid voltage swings. The load resistance is that of the plate-feed resistance and the grid leak of the next tube in multiple.

4. If a battery of power tubes in multiple is employed, so that the grids constitute a considerable capacity load, or if any of the earlier tubes have very high internal resistance, or are fed through very high plate resistances, calculation should be made of the magnitude of the capacity load at the highest frequency which the amplifier must handle. Owing to the simultaneous swinging of the plate potential the effective capacity of a tube grid may be several times the grid capacity as measured with plate and filament grounded. The capacity reactance of the grid must be high compared with both the internal and external plate resistance of the previous tube; otherwise distortion may result, either because of reduced amplification of the high frequencies, or because the actual dynamic characteristic is steeper than estimated (lower impedance load) with resulting curvature.

With a common source of plate voltage for all of the tubes of a multi-stage amplifier, back coupling with consequent oscillations may occur through the plate supply line, if there is enough resistance in the supply so that the power-stage plate current affects the voltage of the supply line materially. If such back coupling occurs, the cure may be to secure a lower resistance supply, or to reduce the variations in the voltage fed to the earlier tubes, particularly the second tube preceding the power tubes, by filters or potentiometer connections. The filters, if of series resistance and shunt capacity, must be effective at as low a frequency as the lowest at which appreciable amplification takes place. Therefore, the filtering is simplified by designing the amplifier not to pass any frequencies lower than really required.

To obtain a given voltage swing on the grid of the power tube may be easier with resistance connection than with an interstage transformer, in spite of the step-up ratio of the transformer. This is because even the best designed transformers drop to an impedance comparable with the tube resistance at high frequency owing to capacity on the secondary side, and at low frequency owing to magnetizing current. This low impedance load on the tube may greatly reduce the plate voltage swing, obtainable without distortion.

Output Transformers

If the output of the power stage goes through a transformer, the design of the transformer follows the general principles of audio transformer design, of which the following is a summary:

1. The impedance at the terminals of the tube is equal approximately to the load impedance multiplied by the square of the ratio of primary to secondary turns, and the turn ratio should be chosen to give the desired impedance at the tube.

2. With the secondary open circuited, the primary reactance should be at least equal to the effective load impedance on the primary side, at the lowest frequencies to be passed.

3. The leakage reactance, found by measuring the reactance of one winding with the other short circuited, should be low compared with the effective load impedance at the highest frequencies in the working range.

4. The winding resistance loss should be low compared with the power supplied to the load.

5. If the direct current component is sufficient to saturate the core, it will frequently be found that the same number of turns gives more inductance with an air gap in the magnetic circuit than without. The air gap should be just sufficient to prevent saturation. The inductance for a given number of turns is then practically proportional to the core cross section, and a heavy transformer is the price of efficiency. If the required air gap is very short, 0.002 in. or 0.005 cm. or less, there may be an advantage in using special high permeability core material, while with longer gaps, 0.010 in. or 0.025 cm. or more, ordinary transformer steel is satisfactory.

The Single-Phase Induction Motor

BY L. M. PERKINS[1]

Member, A. I. E. E.

Synopsis.—*The operation of the single-phase induction motor is presented according to the crossfield theory as distinguished from the theory of oppositely rotating fields. The mathematics used require only a knowledge of algebra and trigonometry and no factors, such as crossfield iron loss and crossfield magnetizing current, are neglected.*

In addition to the derivation of the vector diagram, its transformation into an accurate circle diagram, which requires no assumption except sine wave voltage and primary field distribution, is shown. The result is a circle diagram practically identical with that derived by Branson (A. I. E. E. PROCEEDINGS, June, 1912) from comparison of the two-phase and single-phase induction motors, except that the derivation should be more easily followed and the result is a simpler diagram to construct and use.

THE single phase induction motor consists of a primary winding connected to a source of alternating potential and placed in inductive relation to a short-circuited secondary winding which can move relative to the primary winding. A complete iron path, except for the air gap necessary to allow relative motion between the two windings, is provided for the flux which interlinks the two windings. This interlinking flux is produced by the primary winding because of its connection to a source of alternating potential, and it is the effect of this flux on the short-circuited secondary winding in which we are interested.

The motor is shown schematically in Fig. 1. Although the secondary is considered as being wound with a number of individually short circuited coils, in practise this construction is not used as it is mechanically so much easier to short circuit all the coils to each other by means of common end rings. If the resistance of the end rings is negligible with reference to that of the bars, the two systems give identical results. Although high resistance end rings tend to distort the distribution of the secondary current from that of a true sine wave, this effect is negligible in practise so it will not be considered in this analysis. We will assume that the primary winding is so distributed as to produce a sine wave field form, and that the impressed voltage has a sine wave form.

In addition to the interlinking flux mentioned above, there are leakage fluxes around the different windings which do not link with all the windings. As shown in Fig. 1, there is a flux ϕ_{LP}, threading through the primary winding in addition to the mutual flux ϕ_m, which threads through both primary and secondary windings. Also there is a leakage flux ϕ_{LS} threading through the secondary but not the primary. Furthermore, there is another flux ϕ_C, as will be shown later, which does not thread the primary winding but only the secondary along an axis at right angles to the axis of the primary flux. The total flux threading through the primary is $\phi_{LP} + \phi_m$ which we will call ϕ_1, while the total flux threading through the secondary along the axis of the primary is $\phi_{LS} + \phi_m$ which we will call ϕ_2, and the total flux threading through the secondary at right angles to the primary axis is ϕ_C. In addition to being threaded by fluxes each coil cuts fluxes.

A voltage is generated in a coil by a change in the total flux threading the coil, whether this change is caused by a change in the total amount of flux; or whether, with a constant flux, the coil turns so as to be threaded by more or less of the total flux. The voltage induced in a coil by a change in the total flux is generally known as a transformer voltage and is proportional to

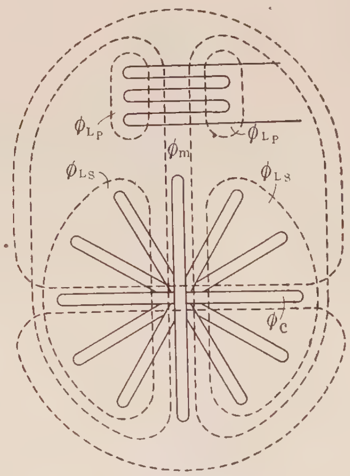


FIG. 1

the frequency of variation of the flux and to the total flux. The voltage induced in the coil as it turns so as to include more or less of the total flux is known as the cutting voltage and is proportional to the speed of cutting and to the density of the flux at the point where the coil cuts it. If the flux is varying as the coil turns the net voltage generated is the sum of the voltage generated by transformer action and cutting action.

We will assume an alternating flux ϕ_2 threading the secondary along the primary axis and will investigate the voltages generated in the various coils by their cutting this flux, and the voltages generated in the same coils due to the alternation of this flux through the coils. Also we will find what other voltages, currents, or fluxes are produced by these voltages.

---

1. Westinghouse Electric & Mfg. Co.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-13, 1925. Complete copies available upon application at headquarters.

A coil at a, Fig. 2, will not cut any of the flux ϕ_2, while a coil at d will cut the flux ϕ_2 at the point of maximum density. The voltage generated in the coil a will then be zero while that generated in coil d will be a maximum. Since the flux ϕ_2 is assumed to have sine wave distribution, the voltage generated in any coil will be proportional to the sine of the angle between that coil and the coil a. This voltage causes a current to flow in each coil and these currents produce a flux ϕ_c along the axis at right angles to the original flux ϕ_2. We will assume that this flux has a sine wave

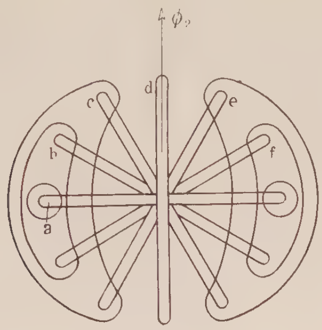


FIG. 2

distribution, although this assumption will have to be justified later. Since the flux ϕ_2 is alternating the voltages generated in the coils by cutting this flux will also be alternating voltages, having maximum values at the time ϕ_2 is maximum and minimum values when ϕ_2 is minimum. The flux ϕ_c will also alternate because the currents producing this flux alternate with the voltages producing them. The alternating flux ϕ_c induces a

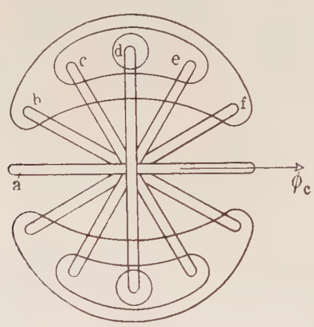


FIG. 3

transformer voltage in the coils threaded by this flux. Since the coil d includes all of this flux the voltage induced in it will be a maximum while the voltage induced in the coil a will be zero as it is not threaded by any of this flux. As we have assumed sine wave distribution of the flux ϕ_c the transformer voltage induced in any given coil will be proportional to the sine of the angle of the coil from the coil at a. Then in coil d there is a voltage E_3, Fig. 4 induced by the coil cutting the flux ϕ_2 and this voltage is in phase with this flux, as shown above. In addition to this voltage, another voltage E_6 is generated in this coil by transformer action of the flux ϕ_c. This voltage lags 90 deg. behind the flux ϕ_c because the transformer voltage always reaches its maximum 90 deg. later than the maximum of the flux which generates the voltage. Since the flux ϕ_c is the total flux, produced by the currents I_3, threading through the secondary along the axis at right angles to the primary axis, the only additional impedance to the current I_3 in the coil d is the resistance of the coil d. Then the $I\,r$ drop of the coil d will be overcome by the voltage which is the difference between the voltages E_3 and E_6, or $I_3\,r_2$ in Fig. 4. Due to iron loss, the flux ϕ_c is not exactly in phase with the current I_3 but lags slightly behind by the angle λ. For this reason, the voltage $I_3\,r_2$ is not exactly at right angles to the voltage E_6. We will assume in this analysis that the iron loss is proportional to the square of the flux density in the iron, which is very close to the truth. With this as-

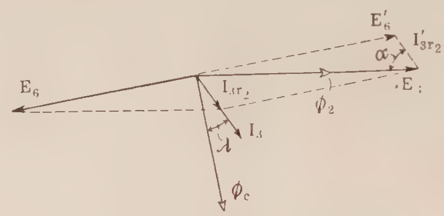


FIG. 4

sumption, the angle between the current I_3 and the flux ϕ_c is constant. Since there is no other winding threaded by the flux ϕ_c, than the secondary winding, the angle between E_3 and E_6 will remain constant as will the angle between ϕ_c and ϕ_2. Since E_3 depends on the speed, being a cutting voltage, the value of the different vectors will vary through a wide range but this will not vary their relative values nor the angles between them.

There are similar voltages to the voltages E_3 and E_6 generated in each of the coils a, b, c, e and f, although these voltages are not of the same value as the voltages

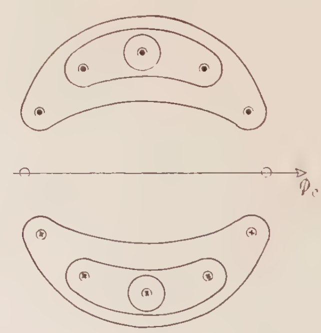


FIG. 5

generated in the coil d as was shown above. However, the voltage E_3' generated in any coil by that coil cutting the flux ϕ_2 will have the same phase as the voltage E_3 generated in the coil d by cutting the same flux. In the same way the transformer voltage E_6' generated in any coil by the flux ϕ_c will have the same phase as

the voltage E_6 in coil d but will be smaller. As shown above, these voltages are both proportional, in the different coils, to the sine of the angle between the given coil and the coil at a. It follows then that the difference between these voltages will also be proportional to the sine of the angle between the coil in question and the coil at a. But since the current I_3 in any coil is proportional to the difference between the voltages E_3 and E_6 it follows that the current I_3 in any given coil will be proportional to the sine of the angle between that coil and the coil at a. In other words the currents I_3 are in phase in the different coils and the current is distributed according to the sine law as shown in Fig. 5. It follows

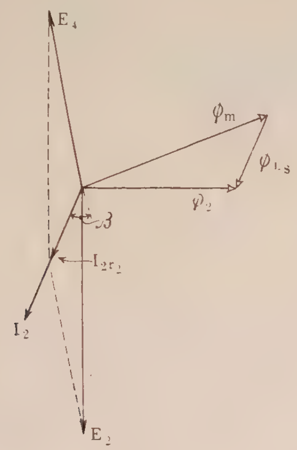


FIG. 6

that the flux ϕ_c produced by these currents will have a sine wave field form. But this was the assumption made in the beginning so that all conditions for the production of the flux ϕ_c with sine wave field form have been met, and that will be its field distribution.

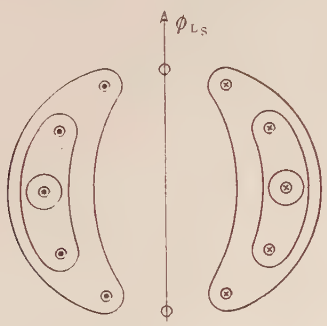


FIG. 7

In addition to these voltages E_3 and E_6 there are two other voltages generated in each coil, first a transformer voltage due to the flux ϕ_2 threading the coil and second a cutting voltage due to the coil cutting the flux ϕ_c. This transformer voltage is maximum in the coil a which is threaded by all of the flux ϕ_2 and minimum in the coil d which is threaded by none of the flux ϕ_2, and is proportional in the different coils to the cosine of the angle between the given coil and the coil at a. Also the voltages induced by the coils cutting the flux ϕ_c is maximum in the coil a and zero in the coil d, being proportional to the cosine of the angle between the given coil and the coil at a, since the flux ϕ_c has sine distribution. The vector diagram for coil a is shown in Fig. 6 where E_2 is the transformer voltage due to the flux ϕ_2 and E_4 is the voltage due to the coil a cutting the flux ϕ_c. E_2 lags 90 deg. behind ϕ_2 while E_4 is 180 deg. from ϕ_c. Since all leakage fluxes are considered in ϕ_2 the voltage difference between E_2 and E_4 will overcome the $I\,r$ drop of the coil a and force a current I_2 through the coil in phase with this voltage difference $I_2\,r_2$. Since both E_2 and E_4 are proportional to the cosine of the angle between any given coil and the coil at a, the current I_2 in that coil will be proportional to the cosine of the angle between that coil and the coil at a. It follows that the current I_2 will be distributed in the various coils according to the sine law as shown in Fig. 7.

In any other coil than a or d all four voltages E_3, E_6, E_2 and E_4 will be generated and the net current in that coil will be proportional to the net difference between all these voltages. However, this net current will

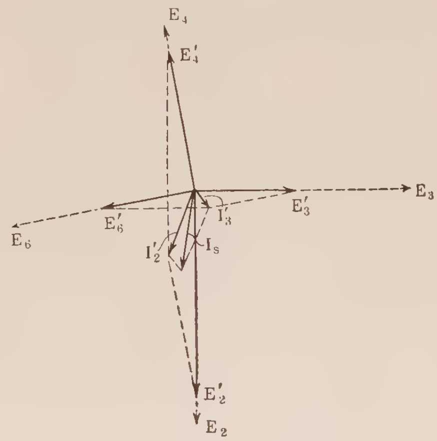


FIG. 8

be equal to the sum of the two currents I_3 and I_2 assumed to flow in the given coil in the above analysis. It makes no difference whether the net current or the two components are considered. Fig. 8 shows the vector diagram for the coil b 30 deg. from coil a. As shown, the total current I_s is the sum of I_3^1 and I_2^1, the voltages E_3^1 and E_6^1 being one half (or sine 30 deg.) of their values in coil d while the voltages E_2^1 and $E_{,}^1$ have .866 (or cos 30 deg.) of their values in coil a.

As shown in Fig. 5, the current I_3 is so distributed in the secondary as to produce no ampere turns along the primary axis, and will not affect the primary winding directly. However, the currents I_2 are so distributed as to act directly on the same flux path as the primary winding so that this current will be transferred to the primary by transformer action.

The flux ϕ_c is the total flux produced by the currents I_3 but the currents I_2 produce a leakage flux ϕ_{LS} in phase with I_2 along the primary axis and as we saw above the flux ϕ_2 is the sum of ϕ_m and ϕ_{LS}. Therefore,

the flux ϕ_m is the difference between the flux ϕ_2 and ϕ_{LS}, as shown in Fig. 6.

In order to force the flux ϕ_m (Fig. 9) across the air gap a resultant magnetizing current must flow in the primary winding producing ampere turns slightly leading the flux ϕ_m by the angle λ_1. (This angle is caused by the iron loss as we saw above.) But before

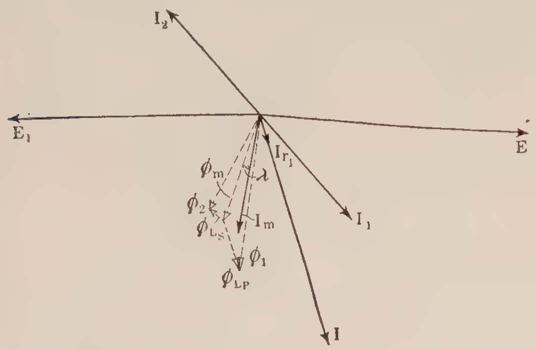


FIG. 9

these ampere-turns can act on the flux path the ampere-turns produced by the currents I_2 acting on this same path must be neutralized by equal and opposite ampere turns produced by the primary winding. Then the total primary current will be equal to the sum of a current I_1 (Fig. 9) equal and opposite to the secondary current (assuming one to one ratio) and a magnetizing current I_m leading the flux ϕ_m by the angle λ_1. The total current will be I in Fig. 9.

Due to this current I a leakage flux ϕ_{LP}, in phase with I is produced threading the primary winding as shown

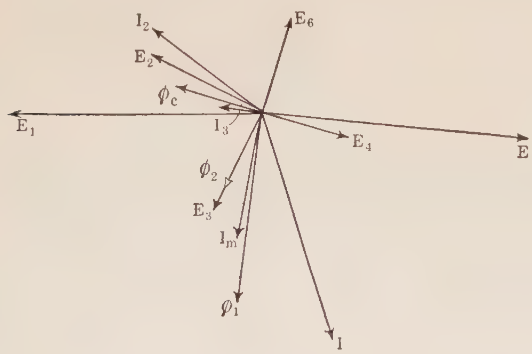


FIG. 10

in Fig. 1, and the total flux threading the primary is ϕ_1 the sum of ϕ_m and ϕ_{LP} as shown in Fig. 9. Due to this flux ϕ_1 a transformer voltage E_1 is induced in the primary winding and the voltage difference $I\,r_1$ between the line voltage and this transformer voltage, forces the current I through the resistance of the primary winding.

The complete vector diagram for the conditions assumed is shown in Fig. 10. Although Fig. 10 shows the complete diagram, it is in such form as to make it very hard to follow such changes as are produced by a change in speed. A simplified diagram which shows all the component vectors is shown in Fig. 11. As will be noted, the two component primary currents I_1 and I_m are considered instead of the total current I, and since I_2 is equal to I_1, the net result is as though the current I_2 flows through both primary and secondary windings while an additional magnetizing current, I_m flows through the primary winding only. There is an additional magnetizing current I_3 in the secondary but as was shown, it does not directly affect the primary. The voltages $I_m\,x_1$, $I_2\,x_1$ and $I_2\,x_2$ are reactance voltages

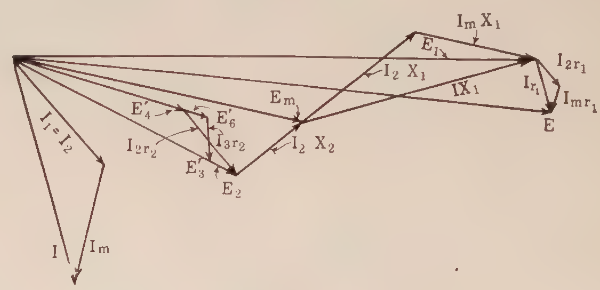


FIG. 11

generated in the windings by the leakage fluxes produced by the currents I_m in the primary and I_2 in both primary and secondary. The voltage $I\,x_1$, which is the sum of $I_m\,x_1$ and $I_2\,x_1$ is the transformer voltage produced in the primary winding by the total primary leakage flux ϕ_{LP}. $I\,x_1$ is at right angles to ϕ_{LP} (Fig. 9). In the same way $I_2\,x_1$ and $I_2\,x_2$ are at right angles to and proportional to I_2. $I_m\,r_1$ has the same phase as I_m while $I_2\,r_1$ and $I_2\,r_2$ have the same phase as I_2.

For the time being we will consider that the primary resistance is zero and that there is no primary iron loss, so that I_m is in phase with ϕ_m and λ_1 is zero. Later we will show the effect of these two losses on the diagram. With this assumption, the vectors E and $I\,r_1$ $(= I_m\,r_1 + I_2\,r_1)$ drop out and the diagram which we are considering is shown in Fig. 12.

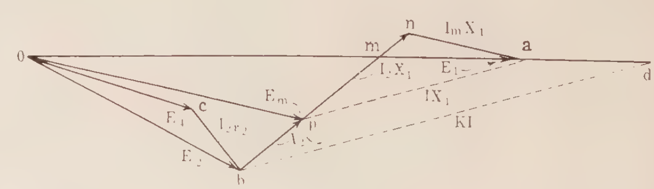


FIG. 12

Since I_m is in phase with ϕ_m, $I_m\,x_1$ will be parallel to E_m because both $I_m\,x_1$ and E_m, being transformer voltages, are at right angles to the current producing the transformer flux. Also we know that $I_m\,x_1$ will have a constant ratio to E_m because $I_m\,x_1$ is the voltage generated by a leakage flux produced by the current I_m while E_m is the voltage generated in the same winding by the useful flux ϕ_m produced by this same current I_m. The ratio between $I_m\,x_1$ and E_m is the ratio between

the permeance of the leakage flux path and the permeance of the useful flux path. If we let $\frac{E_m}{I_m} = z_m$, $\frac{E_m}{I_m\, x_1}$ will equal $\frac{z_m}{x_1}$ where $\frac{z_m}{x_1}$ is the ratio between the permeance of the useful flux path and the permeance of the leakage flux path.

Since E_m and $I_m\, x_1$ have a constant ratio, regardless of other changes in the diagram, it follows that the lines $o\, m$ and $m\, a$ in Fig. 12 are proportional and have a constant ratio (similar sides or similar triangles $o\, p\, m$ and $m\, n\, a$) and that the point m is a fixed point on the line $o\, a$ regardless of other changes in the diagram. Furthermore because $p\, m$ and $m\, n$ are the other sides of these same triangles, they will also be similar and, therefore, proportional to $\frac{z_m}{x_1}$.

$$\frac{m\ n}{p\, m} = \frac{x_1}{z_m} \qquad \frac{m\, n + p\, m}{p\, m} = \frac{z_m + x_1}{z_m}$$

$$m\, b = p\, b + p\, m = I_2 \left(x_2 + x_1 \frac{z_m}{z_m + x_1} \right)$$

Since x_2, x_1 and z_m are constants, it follows that the line $m\, b$ is proportional to I_2.

The line $p\, a$ is proportional to $I\, x_1$ and therefore to I, but we do not wish to have to find the point p in the final diagram so we will find another line from b which will be proportional to I. From b draw the line $b\, d$ parallel to $p\, a$ until it intersects $o\, a$ at d. Then $\frac{b\, d}{p\, a} = \frac{m\, b}{m\, p}$. But $\frac{m\, b}{m\, p}$ is a constant, so it follows that $\frac{b\, d}{p\, a}$ is a constant and $b\, d$ is therefore, proportional to I, since $p\, a$ is proportional to I.

Since the sides $m\, b$ and $m\, p$ of the similar triangles

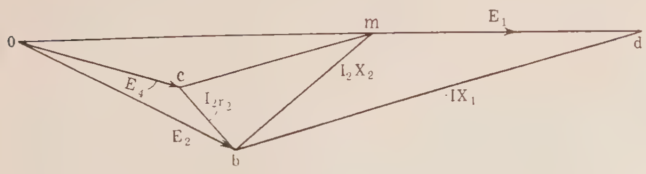


FIG. 13

$a\, m\, p$ and $d\, m\, b$ have a constant ratio and since $a\, m$ is constant as proved above, it follows that $m\, d$ will also be constant and, therefore, that the point d is a fixed point on the line $o\, a$, regardless of any changes in the diagram due to changes in the load or speed of the motor.

If $o\, m = z_m$, then $m\, a = x_1$ and $a\, d = x_2 \left(\frac{z_m + x_1}{z_m} \right)$

$$o\, d = z_m + x_1 + x_2 \left(\frac{z_m + x_1}{z_m} \right)$$

$$\therefore \frac{o\, m}{o\, d} = \frac{z_m^2}{(z_m + x_1)\,(z_m + x_2)}$$

$$o\, a = z_m + x_1$$

$$\therefore \frac{o\, a}{o\, d} = \frac{(z_m + x_1)\, z_m}{(z_m + x_1)\,(z_m + x_2)} = \frac{z_m}{z_m + x_2}$$

Redrawing Fig. 12, and leaving out unnecessary lines, we have Fig. 13, where $X_2 = x_2 + x_1 \frac{z_m}{z_m + x_1}$ and $o\, d = E_1 \times \frac{z_m + x_2}{z_m}$.

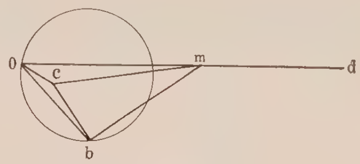


FIG. 14

It was proved in connection with Fig. 4 that the angle between the fluxes ϕ_2 and ϕ_c is constant regardless of other changes in the vector diagram. Since E_2 is 90 deg. from ϕ_2 and E_4 is in line with ϕ_c it follows that the angle between E_2 and E_4 is constant. It has also been proved that the lines $m\, b$ and $b\, c$ are both proportional to the secondary current I_2 so the triangle $m\, b\, c$ will always have the same shape and proportion of parts regardless of its size. We know further that the ratio $\frac{E_6}{E_3}$ is constant, from Fig. 4. It is also true that the ratio $\frac{E_4}{E_6} = \frac{\text{speed}}{\text{syn. speed}}$ because E_4 is the voltage generated in the coil a by putting the flux ϕ_c while E_6 is the voltage generated in the identical coil d by transformer action of the same flux ϕ_c and the cutting voltage becomes equal to the transformer voltage at synchronous speed. In the same way $\frac{E_3}{E_2} = \frac{\text{speed}}{\text{syn. speed}}$ Then it follows that $\left(\frac{\text{speed}}{\text{syn. speed}} \right)^2 = \frac{E_4\, E_3}{E_6\, E_2} = \frac{E_4}{E_2}$ times a constant. Knowing these relations, the effect of changes of load on the diagram can be followed more easily.

If the load is decreased, the triangle $m\, b\, c$ becomes smaller while if the load is increased, the triangle becomes larger. But, regardless of its size the vertices b and c must remain on the opposite sides of the constant

angle $b\,o\,c$ having its vertex at o. In order to fulfill these conditions the angle $b\,o\,c$ must swing down as the triangle $m\,b\,c$ increases in size. Fig. 14 shows how the diagram changes with reference to that shown in Fig. 13 when the load is increased over that in the case of Fig. 13. Since the line $o\,c$ is much shorter, in proportion to the line $o\,b$, in Fig. 14, than it is in Fig. 13, it follows that the speed for the condition of Fig. 14 will be lower than that for Fig. 13. If the line $o\,c$ is

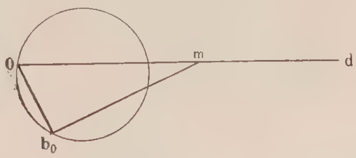


FIG. 15

made equal to zero or in other words, the speed is zero, the diagram changes to that shown in Fig. 15. If, on the other hand, the load is decreased so that $o\,c$ becomes longer and the triangle $b\,o\,c$ swings up, at synchronous speed the diagram takes the form as shown in Fig. 16. In this case $o\,c$ represents both E_4 and E_6 while the line $o\,b$ represents both E_3 and E_2. Then triangle $b\,o\,c$ will be similar to the triangle shown in dotted lines in Fig. 4 and composed of the sides E_3, E_6^1, and $I_3\,r_2$. It is evident that, since the line $b\,c$ coincides with the line $I_3\,r_2$ and $b\,c = I_2\,r_2$, at this speed I_2 will equal I_3.

If two circles are drawn on similar parts of the hypothenuse and one leg of a right triangle, any right triangle having one vertex at the vertex of the original triangle and the other two vertices on the respective circles will be similar to the original triangle; and the two vertices on the circles will lie on the two sides of a constant angle having its ver-

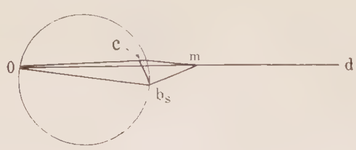


FIG. 16

tex at the intersection of the two circles. These are the conditions to be fulfilled in the diagram above as the load changes, namely that the triangle $m\,b\,c$ must always be the same shape with its vertex at the point m and the two vertices b and c must lie on the two sides of the constant angle $b\,o\,c$, between the voltages E_2 and E_4. Therefore, the point b will follow a circle as the load changes while the point c will follow another circle as the load changes. It is then necessary to determine the location of these circles with respect to the line $o\,d$.

A circle is determined by three points on its circumference. We know three points on the circle locating the point b as follows.

First, both circles must pass through the point o, as the vertex of the constant angle must lie on their intersection.

Second, Fig. 15 gives the location, b_o, Fig. 17, of the point b for zero speed conditions.

Third, the diagram of Fig. 16 gives the location, b_s Fig. 17, of the point b for the synchronous speed condition.

Then, the first circle locating the point b can be drawn through these three points. The second circle is determined from the first by the use of the first proposition in Appendix A. A line $m\,b_2\,b_1$ is drawn from m through the center of the first circle (Fig. 17) and on this line as one leg, the triangle $m\,b_1\,c_1$ is constructed similar to the triangle $m\,b_o\,o$. Then the line $c_1\,c_2$ is laid off so that $\dfrac{c_1\,c_2}{b_1\,b_2} = \dfrac{c_1\,m}{b_1\,m}$; $c_1\,c_2$ is the diameter of the second circle.

Then any line such as $m\,b$ drawn to the first circle

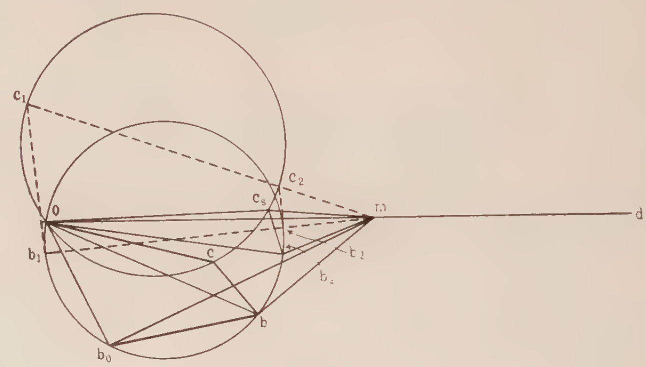


FIG. 17

and the line $b\,c$ at right angle to $m\,b$ form the two legs of the right triangle showing the voltage drops due to the load current and the line $o\,c$ represent E_4 while the line $o\,b$ represents E_2. Since speed is proportional to $\sqrt{\dfrac{E_4}{E_2}}$ it follows that the speed for the load shown by the line $m\,b$ can be found from the lengths of $o\,c$ and $o\,b$. It will be shown later that the torque produced may also be found from the two lengths $o\,c$ and $o\,b$. It has already been shown that the primary current is represented by the line $d\,b$ in amount but that $d\,b$ is at right angles to the current I, while $m\,b$ represents the secondary current in amount, but 90 deg. out of phase. Fig. 17, therefore, shows speed, torque, primary current and secondary current and the phase of the two currents. This diagram may be very much simplified without destroying its usefulness.

Since the line $o\,c$ is the only one determined by the second circle, it is very desirable to find a line in the first circle proportional to $o\,c$. Such a line proportional to $o\,c$ is the line $b\,b_o$ Fig. 17.

So far we have neglected the primary iron loss and the primary copper loss in drawing the diagrams.

It is justifiable to assume that the total primary iron loss is constant if E_1 is constant. This loss may be considered as being supplied from the line by means of a small additional current I_{Fe} flowing through the primary in addition to the current I, considered so far. Since $b\ d$ represents I in amount but is 90 deg. from the proper phase, if we wish to add the current I_{Fe} to I we may do so by drawing a line $d\ o^1$, Fig. 19, representing I_{Fe} to the same scale as $b\ d$ represents I and at right angles to its correct phase. Then the total primary current I^1 will be $o^1\ b$ Fig. 19, to the same scale as $b\ d$ represents I.

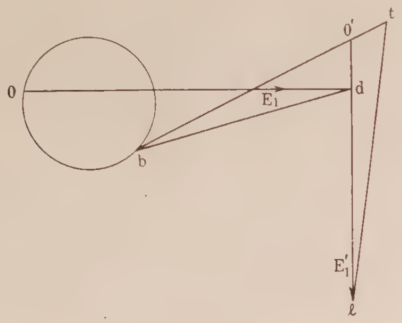


FIG. 19

Due to this current I^1 there is a voltage drop $I^1\ r_1$ in the primary caused by the primary resistance r_1. This voltage is in phase with the current I^1 and therefor at right angles to the line $o^1\ b$, where $o\ d$ represents the phase of the voltage E_1 and $o^1\ b$ is 90 deg. from I^1. In order to simplify the diagram, we will let $o^1\ b$ represent the phase of the primary currents in which case the primary voltage must be represented by a line

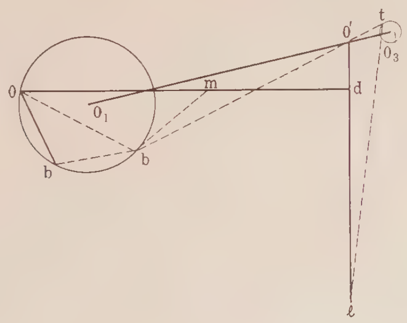


FIG. 20

$o^1\ e$ at right angles to $o\ d$, and the primary resistance drop $I^1\ r_1$ is represented by a line $o^1\ t$, Fig. 19, in line with $o^1\ b$. Since the total line voltage is the sum of E_1 and $I^1\ r_1$, we will lay off $E_1 = o^1\ e$ from o^1 at right angles to $o\ d$ in which case $e\ t$ represents the line voltage to the same scale as $o^1\ e$ represents E_1.

Since $o^1\ t$ and $o^1\ b$ are both proportional to I^1 and the point b lies on a circle at all loads, the point t will also follow a circle. The two circles will have the ratio of diameters of $\dfrac{o^1\ t}{o^1\ b}$ and the centers of the two circles will be on the same line passing through the point o^1. The centers will also be at such distances that $\dfrac{o^1\ o_1}{o^1\ o_3}$ (Fig. 20) $= \dfrac{o^1\ t}{o^1\ b}$ (Fig. 19). Then Fig. 20 shows the complete circle diagram in which the different lines represent the following quantities.

$o^1\ b$ represents primary current in phase and to scale,
$e\ t$ represents line voltage in phase and to scale,
cos of angle $o^1\ t\ e$ equals power factor,
the lines $o\ b$ and $b\ b_o$ will give the speed and torque,

the efficiency may be obtained from $\dfrac{\text{speed} \times \text{torque}}{E \times I^1 \times \cos o^1\ t\ e}$

If secondary current is desired it is represented by $m\ b$ to scale and phase.

It only remains to find the various constants and scales of the lines representing these quantities, so that the numerical results may be read from the diagram, and so that the diagram may be constructed when the constants of the given machine are known.

TORQUE

The secondary coil a Fig. 2, carries the current I_2 as shown in Fig. 6 and has the voltage E_4 generated in it by the flux ϕ_c. Then the torque produced will equal $\dfrac{E_4\ I_2 \cos \beta}{\text{speed}}$. Each of the other coils will have a similar current and, therefore, will produce an additional torque. The total torque will be proportional to that in coil a. In the same way the current I_3 in coil d produces a torque with the flux ϕ_2, as do the currents $I_3{}^1$ in the other secondary coils and the total torque produced by all these currents is proportional to the torque produced by the coil d, or to $\dfrac{I_3\,E_3 \cos \alpha}{\text{speed}}$

Since I_3 is less than 90 deg. from the cutting voltage E_3 as shown in Fig. 4, while I_2 is more than 90 deg. from the cutting voltage E_4 as shown in Fig. 6 it follows that one of these torques will be positive and the other will be negative. Then the net motor torque will be proportional to $\dfrac{I_2\,E_4 \cos \beta - I_3\ E_3 \cos \alpha}{\text{speed}}$.

In order to evaluate this expression it is necessary to go back to Figs. 4 and 6 to find the relations between the various quantities. In Fig. 21, draw E_2 equal to E_2 in Fig. 6 and $E_4{}^1$ equal to but opposite to E_4 in Fig. 6. Then the line $I_2\ r_2$ will be equal to and in phase with the line $I_2\ r_2$ in Fig. 6. Along E_2 lay off a length equal to E_3 Fig. 4. Then a line at the same angle with E_3 as that between E_3 and a vector opposite to E_6 (Fig. 4) will fall along $E_4{}^1$. This is because the angle between E_2 and $E_4{}^1$ equals the angle between E_3 and $E_6{}^1$ since E_2 and E_3 are at right angles and E_4 and E_6 are also at right angles.

We see from Fig. 21, that $I_2 \cos \beta = \dfrac{E_2 \cos \theta - E_4}{r_2}$

and that $I_3 \cos \alpha = \dfrac{E_3 - E_6 \cos \theta}{r_2}$.

but

$E_3 = E_6 \dfrac{\sin\,(90 + \lambda)}{\sin} = E_6 \dfrac{\cos \lambda}{\sin \alpha}$ so that $I_3 \cos \alpha =$

$$\frac{E_6 \left(\dfrac{\cos \lambda}{\sin \alpha} - \cos \theta \right)}{r_2}$$

and $\dfrac{E_3}{E_2} = \dfrac{\text{speed}}{\text{syn. speed}}$ while $\dfrac{E_6}{E_4} = \dfrac{\text{syn. speed}}{\text{speed}}$

so that $I_3 E_6 \cos \alpha = \dfrac{E_2 E_4}{r_2} \left(\dfrac{\cos \lambda}{\sin \alpha} - \cos \theta \right)$

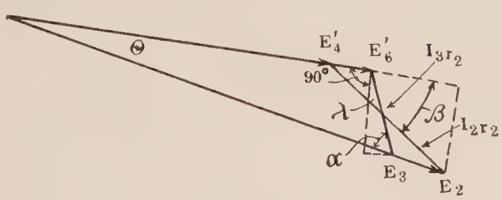


FIG. 21

Then the net torque will be proportional to

$$\left(\frac{E_2 \cos \theta - E_4}{r_2 \times \text{speed}} \right) E_4 - \frac{E_2 E_4}{r_2 \times \text{speed}} \left(\frac{\cos \lambda}{\sin \alpha} - \cos \theta \right)$$

or $$\frac{E_2 E_4 \left(2 \cos \theta - \dfrac{\cos \lambda}{\sin \alpha} \right) - E_4^2}{r_2 \times \text{speed}}$$

From Fig. 21, we see that $\dfrac{\cos \lambda}{\sin \alpha} = \dfrac{I_3 r_2 \cos \lambda}{E_6 \sin \theta}$ but

$I_3 \cos \lambda$ is the current producing the crossfield flux ϕ_c by its magnetizing action ($I_3 \sin \lambda$ furnishes iron loss in the same way as I_{Fe} furnishes primary iron loss) so that E_6 is proportional to $I_3 \cos \lambda$.

Since ϕ_c includes both the flux that goes into the stator (around a path having the same permeance as the path followed by the flux ϕ_m) and the flux following the path of the secondary leakage flux ϕ_{LS}, the total permeance of the path for the flux ϕ_c is proportional to $z_m + x_2$, so that $E_6 = \dfrac{I_3 \cos \lambda}{z_m + x_2}$

$$\therefore \frac{\cos \lambda}{\sin \alpha} = \frac{r_2}{(z_m + x_2) \sin \theta}$$

and the net torque is proportional to

$$\frac{E_2 E_4 \left(2 \cos \theta - \dfrac{r_2}{(z_m + x_2) \sin \theta} \right) - E_4^2}{\text{speed}}$$

SPEED

As has already been shown $\left(\dfrac{\text{speed}}{\text{syn. speed}} \right)^2$

$$= \frac{E_3}{E_2} \times \frac{E_4}{E_6} = \frac{E_4}{E_2} \times \frac{E_3}{E_6}$$

but, $\dfrac{E_3}{E_6} = \dfrac{\cos \lambda}{\sin \alpha} = \dfrac{r_2}{(z_m + x_2) \sin \theta}$

Therefore, speed = syn. speed

$$\times \sqrt{\frac{E_4}{E_2}} \times \sqrt{\frac{r_2}{(z_m + x_2) \sin \theta}}$$

PRIMARY CURRENT I^1

As was shown above $b\,d$ represents I to a certain scale and $o^1\,b$ represents I^1 to the same scale.

but $b\,d = p\,a \left(\dfrac{m\,b}{m\,p} \right)$ and $p\,a = I\,x_1$ while $\dfrac{m\,b}{m\,p}$

$$= \frac{x_1 z_m + x_2 (z_m + x_1)}{x_1 z_m}$$

Therefore,

$b\,d = I\,x_1 \dfrac{x_1 z_m + x_2 (z_m + x_1)}{x_1 z_m}$ or $I \left(x_1 + \dfrac{z_m + x_1}{z_m} x_2 \right)$

and it follows that

$$o^1\,b = I^1 \left(x_1 + \frac{z_m + x_1}{z_m} x_2 \right) = I^1 X_1$$

SECONDARY CURRENT I_2

As was shown above

$$m\,b = I_2 \left(x_2 + \frac{z_m}{z_m + x_1} x_1 \right) = I_2 X_2$$

so it is evident that $m\,b$ does not represent I_2 to the same scale as $b\,d$ represents I^1.

MAGNETIZING CURRENT I_m

When the current I_2 is zero, the only currents in the primary will be the magnetizing + iron loss currents or I_m^1. The actual magnetizing current will be I_m represented by $d\,m$.

Then $d\,m = I_m X_1$

The location of the circle with reference to the line $o\,d$ is more easily found than by drawing it through the three points o, b_o and b_S, as will be shown below in Fig. 22. On the line $o\,m$ construct the triangle $o\,m\,b_o$ having $\dfrac{m\,b_o}{b_o\,o} = \dfrac{X_2}{r_2}$. Then the circle will pass through o and b_o. Unless the secondary resistance is too large, the circle will cut the line $m\,b_o$ at some other point such as b_L Fig. 22. Then for this load the triangle $m\,b_o\,o$ becomes $m\,b_L\,c_L$ and c_L will lie on the line $o\,m$. Since angle $o\,b_o\,b_L$ is a right angle and the three points o, b_o and b_L all lie on the circle, $o\,b_L$ must be the diameter

of the circle. Then the angle $c_L\, o\, b_L$ is the constant angle θ between $o\, c_L$, representing E_4, and $o\, b_L$, representing E_2. Draw the line $b_L\, k$ from b_L perpendicular to $o\, m$ at k.

From Fig. 21, we know that

$$\tan \theta = \frac{r_2}{z_m + x_2 + r_2 \tan \lambda}$$

so that

$$\frac{b_L\, k}{o\, k} = \frac{r_2}{z_m + x_2 + r_2 \tan \lambda}$$

also

$$\frac{b_L\, k}{m\, k} = \frac{r_2}{X_2}$$

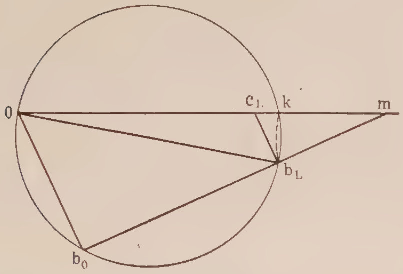


FIG. 22

Therefore

$$\frac{o\, k}{m\, k} = \frac{z_m + x_2 + r_2 \tan \lambda}{X_2}$$

and

$$\frac{m\, k}{o\, m} = \frac{X_2}{X_2 + z_m + x_2 + r_2 \tan \lambda}$$

but

$$o\, m = \left(\frac{z_m}{z_m + x_2}\right)\left(\frac{z_m}{z_m + x_2}\right) \times o\, d$$

so that

$$m\, k = o\, d \times \frac{X_2 \left(\frac{z_m}{z_m + x_2}\right)\left(\frac{z_m}{z_m + x_1}\right)}{X_2 + z_m + x_2 + r_2 \tan \lambda}$$

Therefore

$$b_L\, k = o\, d \times \frac{r_2 \left(\frac{z_m}{z_m + x_1}\right)\left(\frac{z_m}{z_m + x_2}\right)}{X_2 + z_m + x_2 + r_2 \tan \lambda}$$

and $$d\, k = o\, d \times \left[1 - \frac{(z_m + x_2 + r_2 \tan \lambda \left(\frac{z_m}{z_m + x_1}\right)\left(\frac{z_m}{z_m + x_2}\right)}{X_2 + z_m + x_2 + r_2 \tan \lambda} \right]$$

THE FINAL CIRCLE DIAGRAM

Since the line $b\, b_o$ does not represent E_4 to scale, and since E_2 which is represented by $o\, c$, must be multiplied by a constant before using, regardless of whether it is to scale or not, there is no reason for drawing the part of the diagram d, o, o^1, c, b, to the same scale as the part $o^1\, e\, t$. On the other hand, it is more convenient to use a different scale for the currents than is used for voltages. The lines $o^1\, e$ and $o\, b$ will no longer represent E_1 and E_2 to the same scale.

Let S_e = volts per inch to which $o^1\, e$ represents E_1 and S_1 = amperes per inch to which $o^1\, b$ represents I.

Then

$$o^1\, e \text{ (Fig. 23)} = \frac{E_1}{S_e}$$

$$o^1\, d = \frac{I_{Fe}}{S_1} = \frac{\text{watts iron loss}}{E_1\, S_1} (= \tfrac{1}{2} \text{polyphase iron loss})$$

$$d\, o = \frac{E_1}{X_1\, S_1} \left(\frac{z_m + x_2}{z_m}\right)$$

$$d\, m = \frac{I_m}{S_1} \quad \tan \lambda = \frac{I_{Fe}}{I_m} = \frac{o^1\, d}{d\, m}$$

$$d\, k = o\, d$$

$$\left[1 - \frac{(z_m + x_2 + r_2 \tan \lambda)\left(\frac{z_m}{z_m + x_1}\right)\left(\frac{z_m}{z \quad + x_2}\right)}{X_2 + z_m + x_2 + r_2 \tan \lambda} \right]$$

$$k\, b_L = o\, d \frac{r_2 \left(\frac{z_m}{z_m + x_1}\right)\left(\frac{z_m}{z_m + x_2}\right)}{X_2 + z_m + x_2 + r_2 \tan \lambda}$$

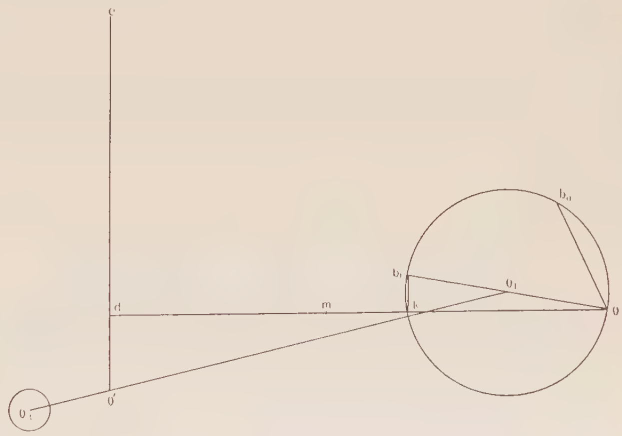


FIG. 23

Then $o\, b_L$ is the diameter of the circle locating the point b with its center at o_1.

$$o^1\, o_3 = o^1\, o \frac{r_1\, S_1}{S_e}$$

$$\text{diameter of circle } o_3 = o\, b_L \frac{r_1\, S_1}{S_e}$$

$$o\,b_0 = \frac{r_2}{\sqrt{r_2^2 + X_2^2}} \left(\frac{z_m}{z_m + x_1} \right) \left(\frac{z_m}{z_m + x_2} \right) \times o\,d$$

Then on this diagram

$S_e \times o^1\,e$ = line voltage

$S_e \times e\,t$ = equivalent line voltage

$$S_1 \times b\,o^1 \left(\frac{o^1\,e}{e\,t} \right) = \text{primary amperes}$$

$$S_1 \left(\frac{z_m + x_1}{z_m} \right) \times m\,b \left(\frac{o^1\,e}{e\,t} \right) = \text{secondary amperes}$$

$$\frac{(o^1\,t)^2 + (e\,t)^2 - (o^1\,e)^2}{2\,(o^1\,t)\,(e\,t)} = \text{per cent power factor}$$

$$K_1 \sqrt{\frac{b_0\,b}{o\,b}} = \text{speed (in rev. per min.)}$$

$$\left(\frac{o^1\,e}{e\,t} \right)^2 [K_2\,(o\,b)\,(b_o\,b) - K_3\,(b_o\,b)^2{}_e] - [\text{Friction (in h. p.) and windage}] = \text{h. p. output}$$

$$\text{Torque oz. ft.} = \frac{\text{h. p. output}}{\text{speed}} \times 84000$$

Efficiency

$$\frac{\text{h. p. output} \times 0.746}{\text{Primary volts} \times \text{primary amperes} \times \text{power factor}}$$

Where

$$K_1 = \sqrt{\frac{r_2}{(z_m + x_2)\sin\theta}} \times \sqrt{\frac{r_2^2 + X_2^2}{X_2^2}}$$

$$K_2 = 0.00134\,\frac{X_2}{r_2}\,\sqrt{r_2^2 + X_2^2} \left(\frac{z_m + x_1}{z_m} \right)^2 S_1^2$$

$$K_3 = 0.00134\,\frac{r_2^2 + X_2^2}{r_2} \left(\frac{z_m + x_1}{z_m} \right)^2 S_1^2$$

DETERIORATION OF IMPREGNATED CABLE PAPER SUBJECTED TO TEMPERATURE ONLY

A report has been made on an investigation of the mechanical deterioration of impregnated cable paper when subject to various temperature tests which have been conducted at the Massachusetts Institute of Technology for a joint committee of the American Institute of Electrical Engineers, the National Electric Light Association and the Association of Edison Electric Illuminating Companies. An abstract of the report furnished by the committee, is given in the following paragraphs.

Introduction

The report is a record of an investigation made for the purpose of determining, by mechanical examination, the rate of deterioration of impregnated paper when subjected to various temperatures in the absence of dielectric stress as used in cable insulation in American practise at the time this test was started,—the object of the research being to determine the maximum safe continuous operating temperature for such insulation as measured by deterioration in mechanical properties.

The research, which was started in 1922, was conducted at the Massachusetts Institute of Technology under the immediate supervision of Professor Vannevar Bush, for the Impregnated Paper Insulated Cable Research Committee,—a joint subcommittee of the Transmission and Distribution Committee of the American Institute of Electrical Engineers, the Underground Systems Committee of the National Electric Light Association and the Committee on Electricity Distribution and Use of the Association of Edison Illuminating Companies. The funds have been practically all contributed by the National Electric Light Association.

It was intended that this first investigation should be of a preliminary character, not only for the purpose of developing methods of testing but also to obtain general data which would be representative of cable in miscellaneous use at that time (1922). It is intended that the tentative conclusions indicated by this first investigation will be confirmed by further work.

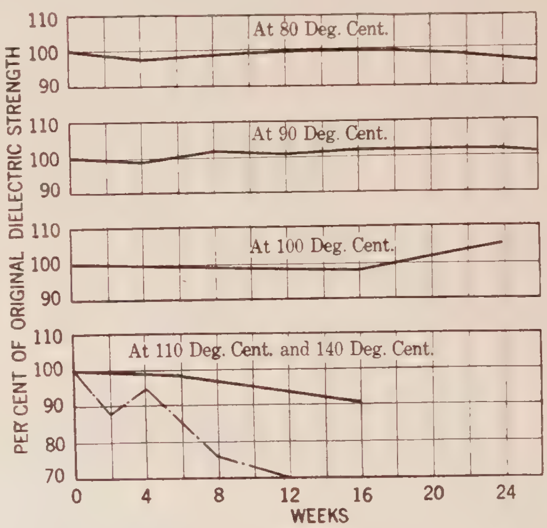


Fig. 1—Curve Showing Deterioration in Dielectric Strength,—Average of all Samples

A large number of samples of cables of various voltages and types, both new and old cable, were furnished to the Institute by a number of the electric operating companies. All of this cable was insulated with manila hemp rope fiber stock paper and all American manufacturers were represented.

Methods and Apparatus

The general procedure was to subject several carefully sealed pieces of each sample of cable to be tested, about six inches long, to various temperatures and remove one piece for test at suitable intervals. The paper on the specimen was then subjected to various tests.

Five specially designed electrically heated ovens were constructed with automatic temperature control. A group of specimens of each of the samples were subjected to temperatures of 80, 90, 100, 110, 120 and 140 deg. cent. respectively. Specimens were removed at intervals and strips of the paper were tested under controlled humidity conditions as follows:

12 tests for dielectric strength between ¼-in. electrodes.

12 tests for tensile strength with a special tensile machine.
12 tests for tearing strength with an Elmendorf tester.
12 tests for bursting strength with a Mullen-type machine.
12 tests for folding endurance with an M. I. T. folding endurance machine.

Number of Samples, Specimens and Tests. Total number of samples of cable tested, 24.

Range of samples, 500 to 50,000 volts, No. O B & S to 2,500,000 C. M., one to four conductors, mineral base compound and rosin base compound.

Total number of specimens tested, 899.

Total number of individual tests of paper, 60,000.

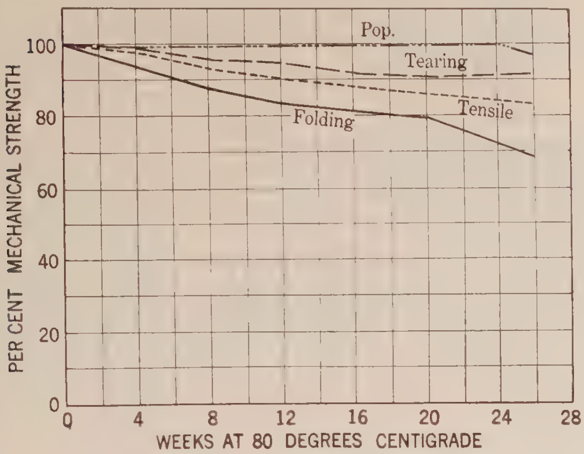


Fig. 2—Curve Showing Deterioration in Mechanical Strength—Average of All Samples at 80 Deg. Cent.

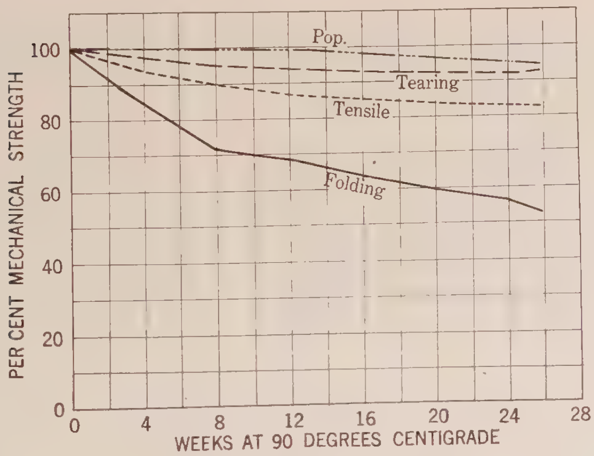


Fig. 3—Curve Showing Deterioration in Mechanical Strength—Average of All Samples at 90 Deg. Cent.

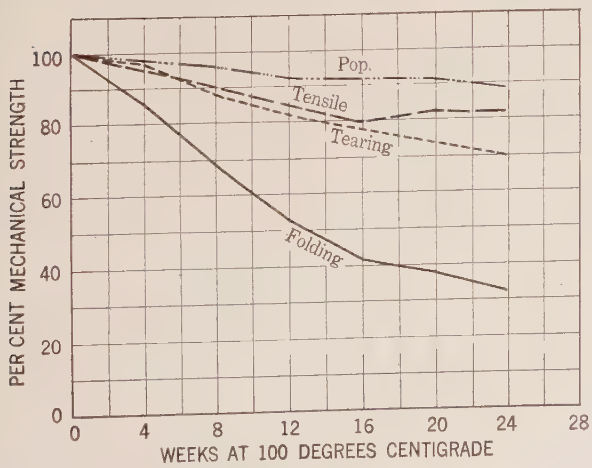


Fig. 4—Curve Showing Deterioration in Mechanical Strength—Average of all Samples at 100 Deg. Cent.

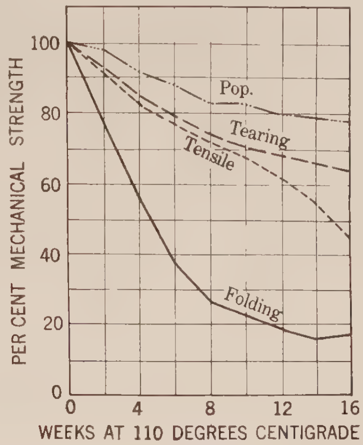


Fig. 5—Curve Showing Deterioration in Mechanical Strength—Average of all Samples at 110 Deg. Cent.

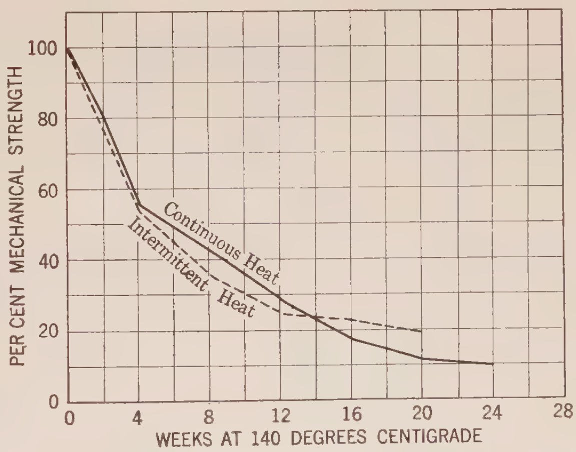


Fig. 6—Curve Showing Deterioration in Mechanical Strength,. Continuous and Intermittent Heating—Average of all Mechanical Tests and all Samples at 140 Deg. Cent.

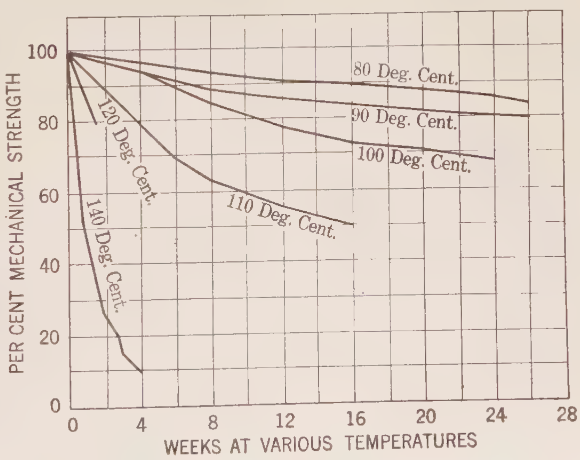


Fig. 7—Curve Showing Deterioration in Mechanical Strength—Average of all Mechanical Tests and all Samples

Summary of Results

The following conclusions are indicated by the data and curves in the very voluminous report prepared by Professor Bush:

1. The dielectric strength of the individual paper tapes remains practically constant, thus confirming the general opinion based on common experience that the dielectric strength of insulations used on cables and other electrical equipment deteriorates very slowly indeed *if it is not subjected to mechanical stresses.* In other words, the maximum temperature at which cables may be continuously operated is not determined by the decrease in dielectric strength. (See Fig. 1.)

2. The folding endurance falls off most rapidly and is therefore the most sensitive of the four mechanical tests of the paper which were made. (See Figs. 2, 3, 4 and 5.)

3. There is apparently no marked difference between the rate of deterioration of the paper saturated with mineral base compound and that saturated with a vegetable base compound. Nor is there apparently any appreciable difference between the results obtained on samples of high voltage cable and of low voltage cable, nor between old cable and new cable.

4. Intermittent and continuous heating to high temperature produce the same deterioration. (See Fig. 6.)

5. The average deterioration in mechanical strength, as shown by the averages of all of the mechanical tests of all samples (*i. e.*, all samples and all tests combined) is shown in Fig. 7. The following tabulation shows the rate of deterioration indicated by these curves expressed on a percentage basis.

Temperature Degrees Cent.	No. Weeks Continuous Exposure	Approx. Deterioration, per cent, Mechanical Strength
80	26	15
90	26	19
100	24	31
110	16	49
120	1½	20
140	4	90

6. It was found that when the tests on the paper removed from the specimens were made in an atmosphere containing 0.008 lb. of water vapor per pound of dry air, the moisture absorbed by the paper after 40 min. exposure would not appreciably affect mechanical tests on the paper. Investigation showed that all of the mechanical tests which were made in this investigation could be performed in about 20 min. The absolute humidity of 0.008 lb. of water vapor per pound of dry air was therefore adopted as a permissible maximum since it could be readily obtained and also afforded an ample margin of time for the tests.

Discussion at Pacific Coast Convention

PAPERS ON SOUTHERN CALIFORNIA EDISON SYSTEM

(Michener,[1] Stauffacher,[2] Shaw,[3] Carlson,[4] Gaylord,[5] Elliott[6])

Pasadena, Cal., October 14, 1924

H. A. Barre: As you know, our initial problem was something very different from building a 220,000-volt line. We had the existing Big Creek Line. We didn't have time to build a new line; we had to get in and make that one work at a higher voltage to carry the additional amount of power that we had to transmit. That was quite a serious problem.

The failures that have occurred on the line have been very instructive. One incident will be sufficient to show the things we ran into. In making the shield rings we worked over a number of different possibilities and finally hit on the idea of using aluminun alloy. We were told by the Aluminum Company that aluminum was a metal which would melt and drop away under heat and hit the ground in a comparatively cool condition and eliminate one of the causes of trouble we had which was setting fire to the whole countryside during our dry summers. Of course you know what happened The concentrations of power were so enormous that the aluminum rings actually ignited and burning pieces fell like a star-shell and set the ground afire. This condition applies to the shield and not the aluminum conductor.

Now, in operating the line we clear away the grass around the towers and in that way eliminate the trouble.

In regard to the matter of relays, I will say that of course we know that relays are not 100 per cent perfect; however, they are better than nothing, very considerably better.

R. Wilkins: I would like to talk on Section 2, the "Protective System." In the past most of the time and energy has been spent on the economic construction of transmission lines and very little time spent on the possibilities of being able to operate those lines economically after they are constructed.

Relays have made such networks as are now operating on the Pacific Coast possible and economically feasible and in the final analysis it is switching and relaying that will determine how many and what kind of lines there shall be to deliver large blocks of power.

In the company by which I am employed it has by trial been proved that it is not feasible to break up that system into sections in times of trouble and the accepted method now is to separate completely the smallest practicable section of that network in such a manner as to give the least possible disturbance.

We use a relay system in which each line is complete in itself and which allows selective directional tripping on any number of lines. In this work relays relying on direction of trouble are superior to those using time for selectivity, and relays using current only for direction are superior to those using both current and voltage on account of power-factor troubles.

With the power available in a large network it is essential that a line in trouble be cleared at a low current value and very quickly in order to prevent serious damage. Emergency repairs on a 500,000 cir. mil line is a real job and takes considerable time.

On the high-tension network of the Pacific Gas and Electric Company we now clear selectively on grounds and unbalances of about 25 per cent and in all cases less than ½ of the normal line current. During the year 1923 out of 1569 high-tension relay operations there were 1490, or 95 per cent correct.

If the relays don't clear a line attached to a system which can deliver approximately half a million k-va., it takes but just a fraction of a second to do considerable damage. The lower current for which you can get the relays set and still make them selective, the better relay system you will have.

J. Mini, Jr: I am glad to see that Mr. Elliott does not hesitate to speak of transmission-line location as an art. In the final success of the working of a transmission-line system, and without a careful consideration of this problem much money can be squandered. Regarding the use of airplane surveys, I will say that we have tried that to a small extent. It gives, as stated in the paper, a comprehensive picture as a whole and saves running a number of preliminary locations, but in the end the final detailed location work is not in any way minimized. An-

1. A. I. E. E. Journal, Vol. XLIII, October, p. 901.
2. A. I. E. E. Journal, Vol. XLIII, October, p. 904.
3. A. I. E. E. Journal, Vol. XLIII, November, p. 1025.
4. A. I. E. E. Journal, Vol. XLIII, October, p. 907.
5. A. I. E. E. Journal, Vol. XLIII, November, p. 1026.
6. A. I. E. E. Journal, Vol. XLIII, November, p. 1028.

other important point is, I think, that it does avoid preliminary advertising that goes with a survey party and which immediately causes property values to sky-rocket over night.

A wide right-of-way is desirable especially through timber country to better avoid accident and forest fires. It is possible, sometimes, to have a narrow right-of-way by arranging to cut all of the tall trees outside of the right-of-way which later might fall across the line. In a rough hillside country it seems important that a proper fill be made for the particular conductor on the uphill side of the right-of-way. While we have, in the past, made office locations, with final checks in the field, we are changing our practice and doing more of the locating directly in the field without the necessity of taking notes to the office and having them returned again later to the field.

The paper by Mr. Gaylord, on the vibration of conductors, is an interesting and important one. We had some trouble from this cause on our long Carquinez span. The details of this trouble and how it was remedied, were discussed by Mr. L. J. Corbett last year at the Del Monte Convention and I will say nothing further here.

It has been our practise to string our conducters with moderate tensions, meaning more sag and lighter towers. This matter was presented in a paper last year by our Mr. Dreyer at the Del Monte Convention.

The paper by Messrs. Carlson and Shaw about "Economic Studies of Transmission Line Design with Particular Reference to the Mechanical Features," is a modified form of Lord Kelvin's law abreast of the times, and includes many factors not thought of in the day of Lord Kelvin. Since some of the intermediate steps are not shown it is not sure whether the corona loss was figured in but I presume it was. It is fortunate that the economic zone extends over such a wide value of kilowatts delivered because we must remember we cannot afford to lower them to the economic limit because when one of these birds that Mr. Michener speaks of comes along we are going to be deprived of that circuit for awhile, at least, and the remaining circuit must have a margin of capacity left to take care of the loss temporarily.

With reference to Mr. Michener's paper, I will say that some flashovers on the Pacific Gas and Electric Company's system have taken place, on both the 110-kv. and 220-kv. systems. The trouble on the 220-kv. line consisted of thirteen flashovers while still operating as a 110-kv. system. There were a number of flashovers on the 110-kv. system and only a few on the 220-kv. system.

I will classify flashovers as of four kinds: (1) That due to being struck directly by lightning; (2) dirty insulators, with light drizzling rain; (3) dirty insulators with dew formation. The two last classes of flashovers occur during the night. We have never had very much experience with dirty insulators where the trouble has occurred in heavy rains, but in light rains, or heavy mists, there has been considerable trouble. The dew-formation trouble is of somewhat a different character. The insulator is dirty, as in the former case, but the trouble usually does not happen until the early morning hours, practically at sunrise, or on cold nights, but the insulator has been lowered in temperature during the night period, and in the early morning hours, practically after the time the sun rises, dew will rise off of the surface of the earth as high as the insulators in the towers. When this highly humidified air reaches the cold surface of the insulator, beads of water are condensed on the surface of the insulator and often form to such a large extent that the different beads are almost connected, making a heavy sheet of water, and, under this condition it is not hard to see how flashovers may occur.

Then, there is the fourth class of insulator flashovers which we call the mysterious type. It occurs on insulators that are in the very best of condition regarding their surface resistance. It occurs in the middle of the day, in the bright sun when the temperature is high and of the insulators that have been examined the surface was found in perfect condition. As I have said, we call those the "mysterious type." We have, for some years, had various devices on the lines trying to see if there was some transient condition of rising voltage which might be responsible, but so far we have not been successful in finding any evidence to that effect. Nevertheless, we still believe that such a possibility is there.

Now, as regards the "bird theory:" I am in perfect accord and willing to blame the bird for a portion of these flashovers of which I call the "mysterious type." We have had absolute evidence that this is so in a few cases. I refer, particularly, to types of strings of insulators that were formed, or hung on the tower in the form of an inverted "V" with the apex at the cross-arm and insulators spread at the base where they were clamped at the wire. I know of one case, in particular, where the flashover was seen by a rancher and the trouble was found by the patrolman after he had notified him. In that case the evidence was so clear that there was no doubt about it. The bird excrement had run down the insulators, which formed a series of steps, being hung at about a 45-degree angle, and the arc absolutely followed the path of this excrement. There have been a great many strings of flashovers found perfectly clean and no evidence of any bird soil on them. We have suspected for sometime that the theory advanced by Mr. Michener was possible. As far back as 1915 we attempted some experiments, which are described in the paper as being credited to Mr. Peek, but we were not as successful, however, as Mr. Peek was, in our experiments. We poured some white-lead paint down alongside the insulator string, but due to the fact that the testing transformer was of small capacity we were not able to establish an arc following the path of the paint. However, I think if the testing transformer had been of a large capacity, as no doubt Mr. Peek's was, we probably would have established a similar experiment. I think the way to make this experiment, however, is actually to take a real transmission line with lots of power behind it, get it out of service and then pour down some liquid of that type. I think the experiment will show, without doubt, that it is entirely feasible to cause flashovers and that they do happen by this very method.

I have some photographs which I took out of a string of insulators which had been on the tower but a few months. The bottom of the string has an insulator shield of spun copper 16 in. in diameter. That string of insulators has in it units 10 in. in diameter and several units 13 in. in diameter. That is an overhang on each side of 1½ inches. The photographs plainly show some of this excrement had caught on the 1½-in. ledge and yet the string of insulators was perfectly clean.

H. C. Sutton: The papers seem to indicate that vibrations are more serious in the longer spans. We had a case with one of our companies where vibrations were observed in 100-ft. spans on a 11,000-volt copper wire where the vibrations were quite excessive in a fairly light wind. I have also heard of a case where vibrations on a similar line were great enough to lift the insulator off the pin. This particular type of pin was of the lead-tip type where the lead had been disintegrated due to the vibration.

We have experienced trouble recently in Connecticut on 66,000-volt lines with normal spans of 800 ft. The lines were built of 2/0 and 4/0 copper. During a severe wind storm with the wind at an exceedingly high velocity, there were four locations in the line, which is 30 mi. long, where the wind apparently deflected from the side of the hill and raised the conductor a distance of at least 8 ft. and wrapped the conductor around the conductor above it. Now this trouble may have been due entirely to the excessive wind and not to vibration, however, vibration may have contributed to the trouble.

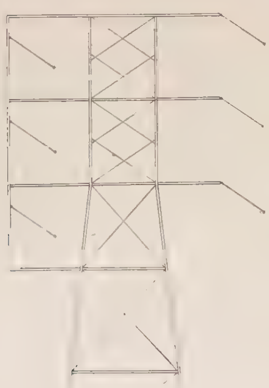
It has also been observed in some places that there are certain spans that are more subject to vibration than others and these spans are not the longest spans in these particular lines. Apparently there is some harmonic condition set up where the vibration reaches a considerable magnitude, the vibration being

sufficient to bring the conductors together. This harmonic vibration has been corrected by changing the sag in the conductor.

Now, in the particular instances where we had trouble with the 66,000-volt lines in Connecticut, we decided to change the sag in the wire. We decided that if a harmonic condition was in any way responsible for the trouble, at least we could correct this condition by changing the sag in the wire. We would like to have sent observers to check up these spans and to determine definitely if a harmonic condition contributed to the movement of the wire, but we felt that we could not afford to run the risk of having a reoccurrence of this trouble.

In looking at some of the high-tension lines in California, I note that there seems to be a considerable number of dead-end points in the line, that is, where the insulators are in dead-end position. Some of these dead-end points are at locations where no angles exist. If vibration is serious, of course the dead-end points should be avoided as far as possible. There are other reasons for avoiding dead-end construction, in that dead-end construction causes other trouble. With the higher voltages the wire loop at dead-end points is excessively long. These loops sometimes swing into the tower and this in turn makes necessary the holding of these loops down by some complicated mechanical means.

In the State of Connecticut where we built a number of 66,000-volt lines, we have avoided the use of dead-end construction as far as possible. We cannot construct our lines on perfectly straight right-of-way. It therefore becomes necessary to install angles in the line. At these locations we have used the so-called pull-down type of construction, installing the pull down on the side of the tower where the line would swing into the tower. On the other side of the tower we allow the conductor to swing away, putting in a single string of insulators. There are other methods of avoiding dead-end construction on angles. A recent method is shown in the illustration. This will allow the use of single



Cut Showing Recent Method of Avoiding Dead-End Construction on Angles

strings of insulators on each side of the tower and will avoid some of the objectionable features of the pull-down type of construction.

D. I. Cone: The problem of the location of a high-voltage line, as so interestingly discussed by Mr. Elliott, has a deep interest for the communication engineers. Actual experience on the Pacific Coast has shown that with these very high-voltage lines the situations of proximity between power and communication circuits are limited to occasional crossings and situations in which there is parallelism at separations of the order of 1000 ft. Under these circumstances the fields of influence, with which we are concerned, are chiefly the magnetic fields, due to current returning through the earth and to balanced load currents. The latter can be cared for by transposing. Thus, the chief problem becomes that of guarding against the effects of earth-return currents arising from star-connected transformers with grounded neutrals, the corona effect that has been discussed here in previous papers, or other causes.

We have two situations to guard against: transient disturbances, at time of flashovers or other accidents, and the steady-state or normal, induction. The data given in the symposium by Messrs. Michener and Stauffacher, on the occurrence of flashovers and the amounts of ground current, are a most valuable contribution to the knowledge of the communication engineers, enabling them better to gage the frequency of occurrence and severity of these disturbances. Likewise, for the steady-state conditions, the data presented in such papers as that of Mr. Wilkins are of great value.

J. A. Johnson: I would like to add a small contribution on the subject of vibration and also on the subject of insulator flashovers.

Some years ago the Canadian Niagara Power Company built a transmission line from their Canadian Plant to Buffalo, which crosses the Niagara River between Fort Erie and Buffalo, with two spans, one of about 1900 ft. and one of 2200 ft. These conductors, originally, were all aluminum and this vibration trouble was experienced on that crossing so severely that the conductors were crystallized at the point of attachment to the towers and in a few cases broke and fell into the river. The solution of the trouble adopted at that time was to interpose a chain between the conductor and the point of attachment to the tower thereby changing the constants of the vibrating system and introducing an interia effect from the weight of the chain so that the vibration was considerably mitigated. However, this solution as applied there was not completely effective. The conductors continued to break and were later changed to copper-clad steel. However, it would seem to me that a solution of this character, with possibly a graded weighting of the conductor as it approaches the point of support, might constitute a solution of this particular trouble.

Now, in the matter of insulator flashovers due to deposits on the insulators: One of the most recent 60-kv. lines which we have built passes in fairly close proximity to the chemical plants at Niagara Falls where one of the products is hydrochloric acid. This acid is stored in a tank outside of the plant proper and this tank gives off a considerable amount of fumes. This particular line is located immediately on the bank of the Niagara River and in the Spring and Fall is subjected to a considerable amount of fog. During these fogs, in the early morning usually, we have had cases where the insulators, four units of Jeffrey-Dewitt, have flashed over. We made an investigation of this trouble, taking samples of the material which we found on the surface of the insulators, which is, when moist, a slimy substance which it is practically impossible to wipe off the insulator. We found it contained a mixture of zinc and calcium chlorides. The zinc chloride came from the galvanizing of the hardware of the insulators, which was completely removed from the iron. The calcium came from a nearby carbide plant which belches into the air a large quantity of lime dust. The solution we found was to wash the insulators and we have been doing that now for nearly a year, both on these particular transmission towers and also at our substation, which is in this same neighborhood. We do this while the line is alive. The substation is a mass of insulators of both suspension and post type. We use a fire hose with about a ¾ in. stream and play it over this mass of insulators, allowing the water to fall on the insulators like a heavy rain. On the transmission towers we have placed pipes up the towers with nozzles arranged to play a stream on the insulators and we periodically visit them with a pump mounted on a truck and drop a suction hose into the river and play the water on to the insulators. We find this effective in preventing this trouble.

It will ill become an Eastern engineer, to whom mother nature has handed her water on a silver platter, you might say, to attempt to suggest to you Western men how you might get the

water to the insulators. However, I have no doubt that your hydraulic engineers, who have shown themselves so efficient in taking water from the place where it is and you don't want it, to to the place where it isn't and you do want it, will find some way to do it if you electrical engineers decide you want the water there.

L. M. Klauber: In washing insulators we have been compelled to reduce the amount of water used because of inaccessibility of the lines and the scarcity of water along the routes. We have recently used an air-compressor outfit, applying a combined air-water spray with a nozzle of the type used in acetylene welding and by this means have succeeded in cleaning insulators using only a few gallons of water per mile of line. We find that with a nozzle of this type an increase in the quantity of water above a certain amount lessens rather than increases the cleansing effect. The air actually does the cleaning and the water serves only to moisten slightly the deposit so that the air can blow it off. This may be of interest to those who operate in arid or mountainous territory.

The work of cleaning insulators by using compressed air is not only better, from the standpoint of water haul, but is likewise a labor saver. We have found that one crew of men, with one compressor, can clean approximately four miles of line per day, whereas, with the old method of washing the insulators by hand, which frequently necessitated actually removing the insulators from the line in order to clean them properly, a crew of men could hardly cover two miles per day. The insulators washed in the new way are washed with greater thoroughness than by hand washing because the air-water jet thorougly cleans the grooves underneath the insulator. We washed about eighteen miles of line about six weeks ago; prior to the washing we were having flashovers at the rate of from three to six per night, depending on the condition of the atmosphere. Since washing them we have not had a single flashover.

PAPERS ON CORONA

(Ryan & Henline[1], Clark & Miller[2], Carroll, Peterson & Stray[3], Clark & Evanson[4], Wilkins[5])

Pasadena, Cal., October 13, 1924

F. W. Peek, Jr.: It is my opinion that apparent discrepancies in the corona papers presented are not due to error in the different investigations, but rather to the difficulty of comparing different conditions. To illustrate what I mean by one example: An aluminum cable strung at Stanford in a grassy field and another strung at Pit after being dragged over the sharp lava rocks should be expected to give different losses near the critical voltage. It would be difficult to predict the result of the mutilation by the lava beds without direct measurements.

I will point out here briefly a few of the outstanding facts concerning my early work which may apply to the present measurements:

Tests were made on indoor lines and on outdoor lines in actual towers under all kinds of weather conditions and at temperatures varying from below zero to 90 deg. fahr. Probably one hundred thousand different readings were taken. Measurements were always duplicated on both the high-and low-voltage sides of the transformer by wattmeters especially calibrated for low power factor. The transformer loss was small. These readings checked. I have great faith in readings made on the low-voltage side because the probably error can be determined readily. It was small. Wave shape and the maximum of the wave was determined by an oscillograph. Voltage was not measured by gaps but determined by calibration of the voltmeter coil with step-down transformers. A small error in voltage is equivalent to a larger error in power. Figs. 1 and 2 herewith give an example of the total loss measured on the high and low side and the net corona loss. It is not difficult to determine the possible error, which is small. In Fig. 3 the losses obtained on high and low sides are plotted on a single curve. There is good agreement.

A study of these data showed that the quadratic law applied very closely above the critical voltage. The criterion for the quadratic is that the curve between the voltage and the square root of the power loss is a straight line. The test for the quadratic law is thus quite simple. Near the critical voltage there was an excess loss depending upon irregularities, dirt, moisture, etc., on the conductor surface. This caused a loss in excess of the quadratic law which followed the probability law. I found no loss due to direct leakage through the air. What excess loss there was below the true critical voltage was found to be due to

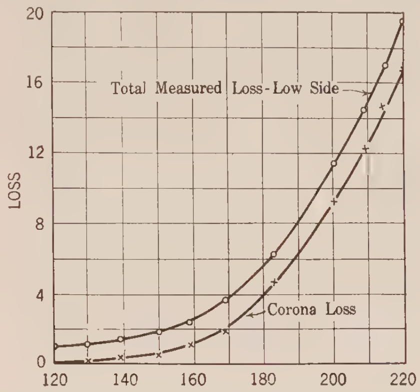


Fig. 1

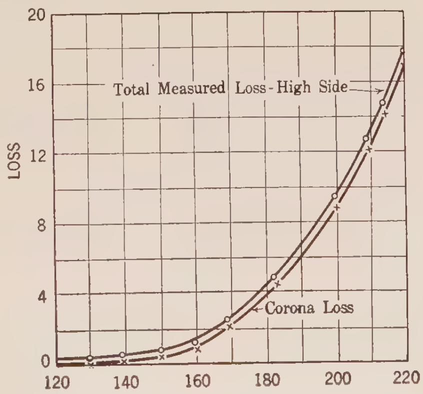


Fig. 2

Figs. 1-2—Comparison of High and Low Side Corona Loss Measurements

actual brushes at local points. The loss at this part of the curve is very sensitive to dirt and moisture on the conductor surface. This is fully discussed in my first paper.

Professors Ryan and Henline presented today a very interesting paper on the theory of the mechanism of corona. I am pleased that the corona values which he has measured and calculated check so well the values calculated by my quadratic law as shown in their table. There is no doubt that part of the corona loss is a per-cycle loss, but in addition there is a component loss which does not depend upon the frequency. There is also considerable corona loss on direct current, The loss on a wire apparently varies for the two halves of the a-c. wave. For this reason, I have never thought of this loss as a hysteresis loss.

I have always thought of the quadratic law as rational. Energy is stored in the dielectric until the critical point is reached on the voltage wave. At this point the brushes start to shor

1. A. I. E. E. Journal, Vol. XLIII, September, p. 825.
2. A. I. E. E. Journal, Vol. XLIII, November, p. 1009.
3. A. I. E. E. Journal, Vol. XLIII, October, p. 941.
4. A. I. E. E. Journal, Vol. XLIII, December, p. 1145.
5. A. I. E. E. Journal, Vol. XLIII, December, p. 1109.

circuit part of the dielectric. Part of the energy is not returned. This energy should be as the square of the excess voltage above the critical voltage.

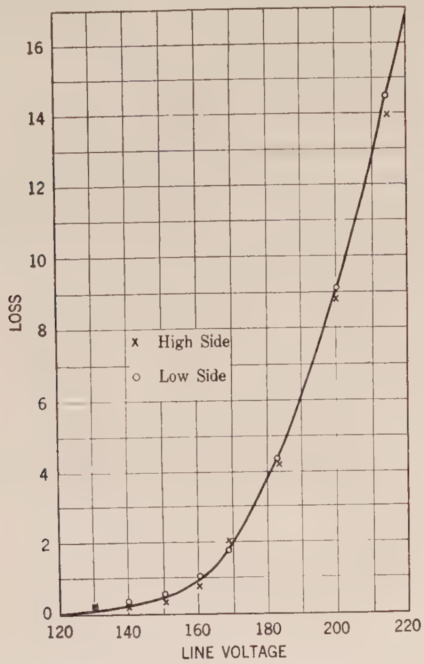


FIG. 3—COMPARISON OF HIGH AND LOW SIDE CORONA LOSS MEASUREMENTS (SEE TABLE I, "LAW OF CORONA," A. I. E. E. 1911)

3/0 Seven-strand cable; 10 ft. spacing; Total length of cond. 3600 ft.; Bar 0.75 cm.; Temp. 10 deg. cent.

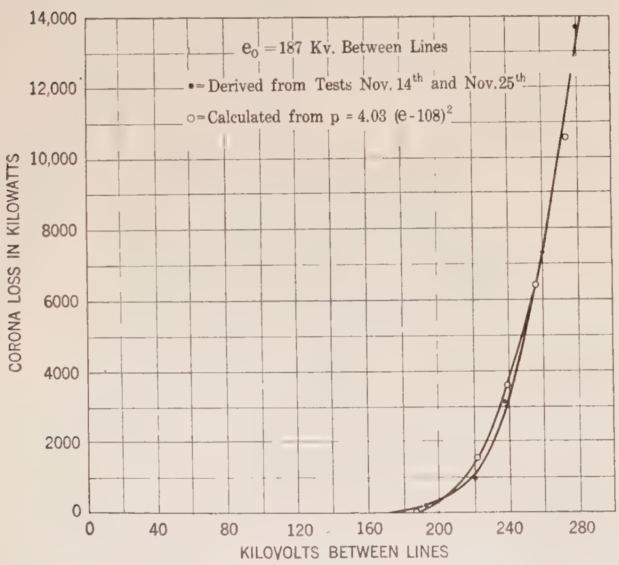


FIG. 4—CALCULATED AND MEASURED CORONA LOSS COTTONWOOD AND WILLIAMS SECTION OF 220,000-VOLT PIT-VACA LINE

Length = 83 mi.; 500,000 cm., 7 by 7-strand copper cable; Rope lay O. D., 0.910 in., M_o = 0.72; Spacing = 15 ft. vertical.

	Nov. 14	Nov. 25	
Bar. Pressure	27.05 in.	26.99 in.	At
Temperature	5.63 deg. cent.	10.0 deg. cent.	Pit No. 1
δ = 1.03			

The measurements of Professors Clark and Evenson are interesting. I would like to call attention to the fact, however, that the correction which they find it necessary to make in order to get the net corona loss is much larger than the transformer-loss correction for measurements made on the low side. Such a correction is uncertain, whether it is made on paper or in the instrument.

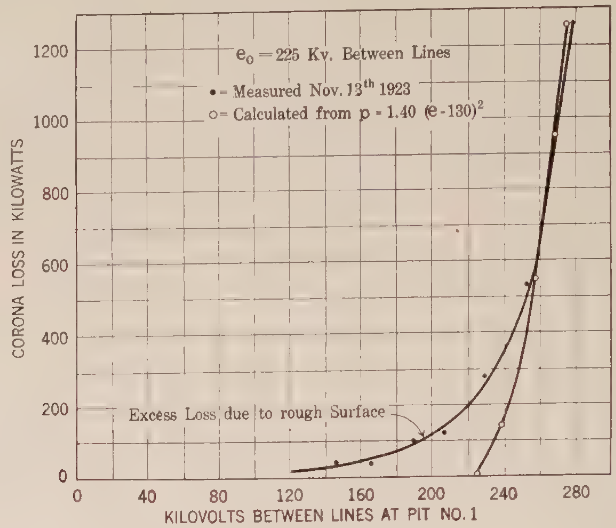


FIG. 5—CALCULATED AND MEASURED CORONA LOSS, PIT TO ROUND MOUNTAIN SECTION OF 220,000-VOLT PIT-VACA LINE

Length = 27½ mi.; 642 cm. 61-strand, steel-core aluminum cable; Concentric Lay O. D. = 1.08 in.; Cable new and scratched, M_o = 0.78; Spacing = 19 ft. horizontal

Bar. pressure	= 26.90 in.	At
Temperature	= 9.2 deg. cent	Pit No. 1
δ	= 0.95	

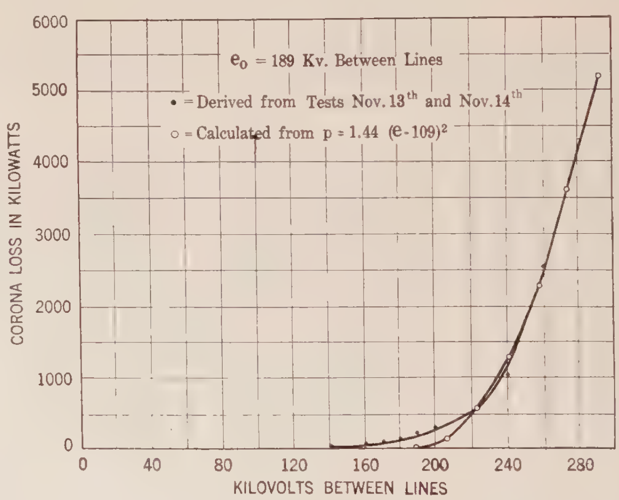


FIG. 6—CALCULATED AND MEASURED CORONA LOSS, ROUND MOUNTAIN TO COTTONWOOD SECTION, 220,000-VOLT PIT-VACA LINE

Length = 32½ mi.; 500,000 cm., 7 by 7 strand copper cable; Rope lay O. D. = 0.910 in.; M_o = 0. 72; Spacing = 19 ft.

	Nov. 13	Nov. 14	
Bar. Pressure	26.90 in.	27.05 in.	At
Temperature	9.2 deg. cent.	5.63 deg. cent.	Pit No. 1

Conditions for this section
Assumed = 28.0 in. and 9.2 deg cent.
δ = 100

The high-voltage wattmeter when fully developed should be a very useful tool.

Mr. Wilkins' measurements are very important from both the theoretical and practical standpoint. Investigations of

this character are of great value to the industry. Two types of conductors are used: Concentric-lay aluminum cable in the lava country of the Pit and rope-lay conductor in the valley. Since the rope-lay conductor is irregular in a uniform way, the surface should not be much affected during stringing. The uniform aluminum conductor should be quite badly mutilated by dragging in the lava and should, for this reason, be expected to give large excess loss near the critical voltage. It is naturally difficult to estimate the effect of such treatment for any particular case. Mr. Wilkins' measurements show this excess loss for the aluminum conductor. The measured and calculated losses check very closely for the rope-lay cable. This is illustrated for the two different types of conductors in Figs. 4 and 5 here-

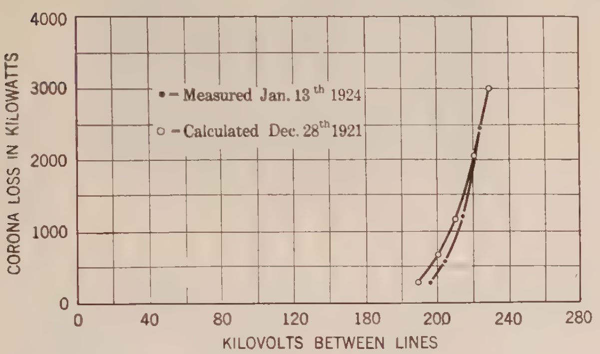


Fig. 7—Measured and Predicted Losses on Williams' to Vaca Section of 220,000-Volt Pit-Vaca Line

Length = 59 mi.
500,000 cm., 7 by 7 strand copper cable
Rope lay O. D. = 0.910 in.
M_o = 0.72
Spacing = 15 ft. vertical
Corrected to standard conditions of temperature and barometric pressure
t = 25 deg. cent.
p = 29.9 in.
δ = 1.00

with giving calculated loss and measured points taken from Mr. Wilkins' paper. Fig. 7 shows the measured and predicted loss for the line. Mr. Wilkins finds that the measured losses do not always follow a quadratic. This should be the case on a long line for the following reasons: There would be at least several critical voltages along the line due to the different conductors, difference in elevation and temperature. The wattmeter reads the sum of the losses for all of the sections at different critical voltages. If the losses in each section follow the quadratic law, the sum of these quadratic curves, which is what the wattmeter reads, could not be expressed by a single quadratic but would be a curve similar to the ones found by Mr. Wilkins. This is shown in Fig. 8. Each section should be calculated separately and added to obtain the total. A small error in voltage would also make a large error in power. I note that there is a considerable difference in voltage measurement on the low side and by the hose on the high side. This would also contribute towards the difference noted.

Mr. Wilkins states that no corrections were made for temperature. This would also cause difference between his measurement and calculations. I would like to ask if loss measurements were also made during the warm summer months. The quadratic law shows that the loss would be much higher at the higher temperature. If Mr. Wilkins has such measurements they would be a check on the quadratic law.

It is my opinion that it will generally not be economical to operate a line above the fair-weather e_o voltage. The loss during fair weather at this voltage is generally not of great importance since the controlling factor is the rain loss. With rain only 10 per cent of the time the greater part of the annual loss would occur during storms.

The large amount of power transmitted on 220-kw. lines will generally require conductors so large that the critical voltage is above the operating voltage. If this does not occur, the diameter of the conductors can be easily increased by a central core to meet this condition. In other words, why have any appreciable loss when it is so readily prevented? The exact calculation of the annual loss is thus not always as important from the practical standpoint as from the theoretical standpoint.

In conclusion, the loss measurements on which the quadratic law was based were made in duplicate on high and low sides of the transformer and were always in good agreement. Voltage was measured by step-down transformer and voltmeter coil. The wave shape was determined by oscillograph.

This law holds over a very large range of voltage as shown by the curves in my discussion of Professor Harding's paper.

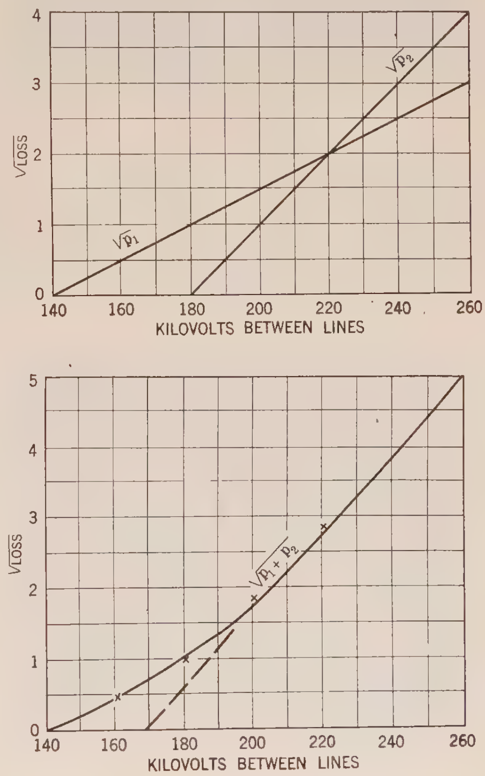


Fig. 8—Corona Loss as Measured on a Long Line with Different Critical Voltages

Upper Curve—Two quadratic corona loss curves with different critical voltages

Lower Curve—If two corona loss curves with different critical voltages are added, the sum cannot be represented by a quadratic, although each component curve is, in itself, a quadratic.

Measurements made in 1924 check those made in 1910 although made by different men with different apparatus.

The reasons for apparent and actual deviation from the law indicated by some of the curves in the papers presented today were for the most part observed and discussed in my 1911 paper. Predicted loss is in good agreement with the actual loss on the 220-kv. lines.

It will generally be desirable to operate below the e_o voltage. If the conductors are not large enough the diameter can be increased by a core.

R. W. Sorensen: The Steinmetz-Hayden paper, entitled High-Voltage Insulation, presented at the 1923 Pacific Coast

Convention held in Del Monte, showed some very interesting phenomena, the reasons for which we would all like to know. Thinking that some Lichtenberg figures might help to work out the reasons, I have some photographs which may also help explain the hysteresis character of corona loss as found by Professor Ryan and his colleagues.

FIG. 9

Fig. 9 is made with about 10,000 volts d-c. applied to two needle points spaced about 1⅜ in. apart. The point at the right is connected to the positive terminal and the one at the left to the negative terminal. In these figures is seen the characteristic difference between the positive and negative records, both as to

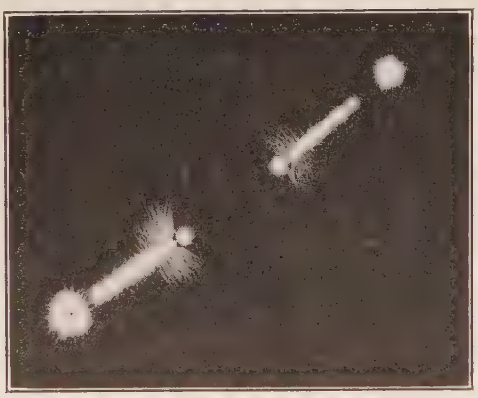


FIG. 10

appearance and distance from the electrode, marked by the emanating electrons.

Fig. 10 shows two similar points with alternating current impressed upon them.

Fig. 11 shows a cylinder and a needle point, the nearest approach one can make to having a plate represent the discharge between a point and a sphere. In this case, the voltage applied was alternating current. The voltage on all slides shown is below visible corona voltage

Fig. 12 shows a double phenomena, the cylinders being charged positively and negatively used in conjunction with negatively and positively charged needle points respectively. This photograph was made by Mr. H. E. Mendenhall, a graduate student at California Institute of Technology.

An examination of these photographs shows the greater range of electron travel from the positive electrode as compared to the range from the negative one.

An inspection of these figures leads one to the logical conclusion that the reason for the results of the tests made by Steinmetz and Hayden is that when a point is connected to the positive terminal, the electrons travel a much greater distance for a given applied potential gradient than is the case when the point is negative and the sphere positive. Extending this reasoning to explain the results of tests which are now under discussion, is it not possible to assume with a fair degree of certainty that this also explains the reason for hysteresis effect of a-c. corona.

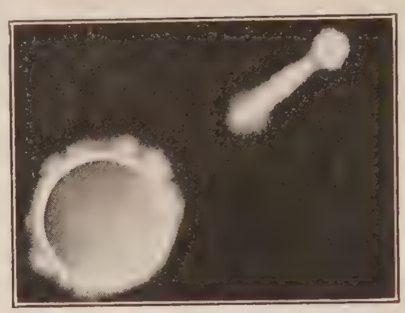


FIG. 11

During the half cycle a conductor is positively charged its electrons have a larger field of travel than during the half cycle it is negatively charged, thus making it impossible to account for a complete balance or neutralization of charges.

W. A. Hillebrand: While the electro-motive force increases up to a certain point your charge is directly proportional until your critical voltage is reached. As you descend the curve and reach zero electro-motive force there is a residue charge which should be neutralized. A somewhat similar relationship occurs during the other half wave. That means that within certain

FIG. 12

limits the energy loss per cycle is constant regardless of frequency. To me that has been extremely significant. The time effect as commented on by Professor Ryan does not enter over the lower range of frequency; as frequency increases the time effect does enter. We have another relation of interest: That you have a loss by electrical conduction which is a nice parabola. Is it possible that at a certain point we begin to develop the self-propagating streamers? That is, the Peek high-frequency effects? If that is so, it is to my mind important that we understand still more about the fundamental periods at which a transmission line will oscillate (I am not referring to the frequency of the line as a whole) in order to determine whether or not the fundamental frequency

is at a point where you will develop the possibility of self-propagating streamers.

A wattmeter that will measure one watt, or a fraction of a watt at 110,000 volts, is, I think, as everyone who deals with measurements will agree, a remarkable achievement. I hope that it will be found possible, through the medium of this instrument, to develop further information with regard to the current-carrying capacity of liquid films that will lead to understanding the question of surface leakage.

For example, there is a transmission line in our neighborhood that has gone out simply due to surface loss over the insulators. It is a 60-kv. circuit. When the line is dead, and suddenly energized, the loss is too great to start it to going.

J. B. Whitehead: In the first of these papers we have a further contribution to the problem of the measurement of small losses at low power factor in high-voltage circuits. It is a problem that has been attacked for years; and which has caused great trouble because of the difficulty of maintaining the current in the voltage circuit of a wattmeter, of whatever type, exactly in phase with the applied voltage.

Professor Ryan's work is notable in three particulars, I think: First of all he is putting the entire wattmeter system in the high side of the line. Ordinarily, in work of this kind, we find that instrument at the central neutral point. He does not eliminate however the problem of screening the voltage coil and resistance.

The next point is the method used for screening the voltage circuit and making certain that the current in that circuit is not only proportional to the voltage, but that it shall be in phase with the voltage. Both of these things must be taken care of. Professor Ryan has done it by adjusting the relation of the series resistance, or voltage multiplier, as he calls it, to the electrostatic field. I like, particularly, the ingenious method that he has used for maintaining a uniform electrostatic potential gradient over the resistance. He has placed it between two external shielding rings and has studied the field between those rings making sure that the water coil, as it spirals down, takes a constantly descending electrostatic potential as well.

The use of water is the third point. I think it is not very common to use water as a resistance. The difficulties are due to low conductivity and to heating. Professor Ryan has attempted to avoid them by letting his water flow continuously and I see no reason why that is not a perfectly sound method for meeting the difficulty provided, only, that the temperature is properly regulated.

It is not, perhaps, as well known in this country as it should be that the screening of such resistances, so as to make sure the electrostatic error is avoided, and a method for studying the degree of such error, and controlling it, has been published. It was published in Germany first by Professor W. B. Kouwenhoven of Johns Hopkins University, and subsequently by Washington University, of St. Louis. It is a very complete examination of this question of electrostatic error in connection with resistances. It is well worthy of examination by anyone who is contemplating making measurements at high values of voltage.

Professor Ryan and his associates in the second paper, are investigating the question why the measurements of different observers on corona loss, particularly, in the initial stages, are not always concordant and are subject to doubt. The first reason, is the question of the accuracy of the measurements to which we have just referred. The second reason is due to the fact which Mr. Peek has mentioned, and which, is also clearly in Professor Ryan's mind, that it is impossible to obtain perfectly uniform conditions on a conductor in the open and, particularly, in a long line of such conductors, with alternators in the character of the conductors themselves, the spacing, etc. Most work that I have done has been within the laboratory where we could control conditions. There is never any doubt in such experiments as to what is going to happen after you have made a number of those experiments and the results may usually be given as definite laws. In the open your conductors are not smooth; you may have cable of various make ups; these cables are scratched and dirty; you no longer have the question of what is the law of corona, but you have the question as to how dirty your wire is and how many needle points it has on it, or how many drops of water it has on it. It seems to me that that is the principal reason why so many of these studies that are brought before us lack the punch of authority.

Now, Mr. Peek, in his first work, met this situation squarely by recognizing the fact and pointing out we must increase the voltage above the initial loss value before we get to the region subject to definite law. We must reach a voltage where the irregular point discharges unite in increasing the diameter of the conductor and making it equivalent to a smooth conductor and for that reason Peek found it necessary to introduce two critical voltages. One was the voltage at which the conductor would start into corona had it been perfectly smooth. The visual critical voltage was something lower.

I am not sure that we are going to get anywhere by trying to study this intermediate range. It seems to me that it is a question of entirely indefinite nature, and the corona voltage may vary from point to point and from line to line. I like very much better the plan adopted by Mr. Peek of simply inserting an engineering constant or factor, having different values for different conditions, into the law for smooth conductors. That seems to me a sound engineering method.

Professor Ryan's second paper deals with this intermediate region of irregular corona formation. He is trying to find some law, as I read his paper, which will enable us to predict what is going to happen within this initial stage. The pictures that he shows and also those by Mr. Peek, make me question whether there is not perhaps something else to the matter. The location of these individual brushes, the fact that they stick as you raise the voltage, and the fact that the pictures show no approach to a uniform appearance as the voltage is raised, makes me ask the question, whether it is permissible to say that above a certain voltage corona becomes a uniform cylinder and that further increase with voltage will be in accordance with a definite law. Frankly, I don't know how to feel about it. Professor Ryan has opened the question anew, and shows that we must study further before we can say that we know all about the law of corona.

I now pass to Professor Ryan's paper in which he is suggesting that the phenomena of corona has a hysteresis character. There have been numerous explanations of the process of breaking down of the air. They ask us to think about the motion of electrons between molecules and to picture the process of ionization by collision. But I don't think that present physical theory is easily followed by engineers. It is, therefore, perhaps just as well if we can confine ourselves to some picture of the loss process due to corona which makes a less extended demand upon our attention. So, Professor Ryan has made this very interesting suggestion that the loss due to corona may take on the character of hysteresis. He has been led to it by the shape of the power curves taken with his electrostatic wattmeter and taken originally, I believe, with the cathode-ray tube.

Magnetic hysteresis is distinctly a molecular phenomenon, so far as we know it. The nearest we can come to picturing the mechanism of it is that it is some kind of a friction between or within the molecules. Magnetic hysteresis, for years, was the only type of hysteresis that we knew anything about. We next heard of dielectric hysteresis, the loss in dielectrics due to an alternating electric field. Here too, such attempts at explanations as we have had, picture these losses as due to some type of successive orientation on the part of the molecule, or the atom, causing frictional loss.

Now, for these reasons, I am raising the question as to whether the use of the term "hysteresis," which implies molecular fric-

tion, is as helpful in explaining corona as the idea of straight electric conduction; that is, conduction through the air by means of the motion of charged molecules or aggregates of molecules known as gaseous ions? You can study the motion of these ions; you can feel them, under certain circumstances; if you put a hole in a grounded cylinder in the middle of which there is a corona-forming conductor, you can feel the motion of ions that come out of that hole under the impetus of the electric field. There are numerous other evidences of conductivity of the air. Experiments with continuous voltage will show you conductivity directly; you can put obstacles in the path and stop the flow of the ions and I don't see exactly how, with Mr. Peek, we are going to think of the hysteresis character of corona, or think of corona as a hysteresis effect and at the same time take care of these evidences of conductivity.

Now, the suggestion of the hysteresis nature of corona by Professor Ryan is based on the shape of the curves taken with the electrostatic wattmeter in which he finds a maximum value of the induction, a shape similar to the magnetic hysteresis loop, and a loss in proportion to the area of that loop, all of which are most suggestive. But it seems to me that the shape of these curves can be completely explained in terms of the conductivity of the air. Taking his Fig. 5, the discharging point is directly opposite one of the plates of the wattmeter and as soon as the point begins to discharge, the plate takes up some charge; that charge is going to stay on that plate because it is insulated, until it is neutralized by an opposite charge in the next half cycle. While the charge is on the plate it will naturally modify the distribution of the electrostatic field that was there before the point began to discharge, consequently, he has a shifting of the sides of his curves, but these remain straight. Why? Because they have a definite charge upon them from the preceding half cycle and he has simply changed the potential of the plate by a uniform amount and the central line of his diagram is carried out to the side of the loop, but always parallel to itself. As he pushes the voltage higher and higher the sides of the cycle will become more and more curved because it takes a longer and longer time to neutralize the charge due to corona on the preceding half cycle.

R. J. C. Wood: I was a little disappointed at the stand that Professor Whitehead took, or, perhaps, I misunderstood him. What I gathered was that we should not try to formulate any laws about this region of corona, which is between the starting point and the point where it follows Mr. Peek's law. On the other hand, Professor Whitehead said we should get all the data we could in that region so that we could establish factors of safety. Perhaps, I misunderstood him entirely and we all mean the same thing. We all want this data because it pertains precisely to that region on the voltage curve, wherein we most probably will have to work for economic reasons.

There is another viewpoint on this question, namely, that in order to employ anything like 220,000 volts there must be a very large block of power to transmit and a very great distance to transmit it in order to make it an economic success. Having that very large block of power and long distance the economic conductor will be so large that corona losses will be practically eliminated.

There are some points in the paper that I would like to mention. The great trouble with all this corona data has been in bringing the results of different observers into conformity. There are one or two things which occur to me which do not seem to have been specifically mentioned, which may account for these differences. One of them is the deposit which forms on the conductor after it has been in use at a high voltage. Our Big Creek line, of aluminum conductors, was first operated at 150,000 volts and down in the lower altitudes where there was considerable smoke and dust in the air the conductor became coated with a black enamel, you might call it. It was hard and so closely adherent to the conductor that it required some force to scrape it off with a knife blade. Up in the higher altitudes, above 3000 or 4000 ft. where the air was pure, that conductor was not so black, and, in fact at the highest altitude of 5000 ft. it was almost as bright after several years as at the time when it was first installed. When we went to 220,000 volts the conductor very quickly blackened, even in the higher altitudes. Now, we noticed when we were running our experimental line, 27 mi. long, previous to the energizing of the total line up to 220,000 volts, that when we first energized that line some new connections we had put in of new bright cable were very luminous and emitted a considerable noise. We could hear the crackling of corona quite a distance, but after the voltage had been on for two or three weeks these conductors blackened like the rest of the line and the noise decreased very much. That brings up the thought that in some of these semi-laboratory tests, by which I mean tests where there is a length of line in the open energized from a laboratory, possibly the conductor may not have reached the ultimate surface condition. For example somebody wants to test a piece of new kind of conductor with a naturally bright surface when it is received, and it is hung up on the experimental line and tested, possibly before it has gone into the steady condition. A line will afterwards be built of that same kind of conductor and after it has been in service for a little while the black deposit may have formed and then, naturally, the tests on the line as a whole will not conform with the laboratory tests made on the new conductor.

I have a suggestion, which may or may not be of any value as to the measurement of these losses. The great difficulty lies in the low power factor and it occurred to me that, perhaps, a way out of the difficulty would be to raise the power factor, and that can be done by putting a synchronous condenser on the end of the line. In case of a long transmission line there would be two advantages, a better power factor at the sending end where the meters were and the ability to control the rise of voltage over the line and have practically uniform voltage over its whole length. The only objection I see would be in evaluating the losses in the condenser, but I believe one could study these and arrive at what they were quite closely.

J. S. Carroll: The water-column resistance used as the multiplier for the high-voltage wattmeter is of vital importance. The studies made at Stanford last gave us a little insight into the solution of some of the problems of electrostatic shielding. To begin with the original water column was built of 75 ft. of ½-in. garden hose. Last year it was shortened to 20 ft. using ¼-in. air hose. Just before coming to the convention some brief measurements were made with a water column 5 ft. long and 0.095 in. in diameter. A stout glass tube was used in this case. On account of this smaller diameter the water pressure had to be raised to about 130 lb. per sq. in. in order to keep the temperature within reasonable limits. The water column was mounted in the vertical position between two horizontal metal plates of sufficient size to produce a fairly uniform field at the center where the water column was located. The bottom plate and the lower end of the water column were connected to ground, the upper end of the column was connected to the instruments and the upper plate was connected directly to the high-voltage terminal of the transformer.

Unfortunately, in this case, water has a very large negative resistance-temperature coefficient, so that the voltage gradient will not be exactly uniform down the column on account of the heating effect of the current. However it is possible to adjust the field between the two plates until it very nearly matches the gradient down the water column. Even if the two fields are not exactly the same throughout their entire lengths the total error produced will be very small on account of the small capacitance of this short water column. In regard to the test as to when the fields are matched, a similar method will be used that was used last year in which the resistance of the water column was decreased by cutting down the flow of water and allowing it to warm

up. There is a little objection to this method but it was not as serious last year as I had thought it was but we are getting down now into corona and related matters, to where we are having to split hairs over those values near the x-axis. To test for correct shielding of this short water column, instead of changing the conductivity of the water by reducing the flow which would change the shielding slightly, we will change the conductivity by the introduction of a salt solution and the temperature of the water will be kept constant by controlling the flow. No doubt there will be a few problems to solve before this method will be free from objection, one of them will be the proper mixing of the solution beforehand to prevent an unsteady flow of current. However with the crude apparatus now set up this method seemed to work very satisfactorily. With the voltage held constant the current was gradually raised from 30 milliamperes to 60 milliamperes. With this arrangement we have an ideal multiplier the multiplying factor of which can be controlled easily and made any value between rather wide limits. Not only can we evaluate error due to the capacitance of the water column and tell when it is eliminated but we can also keep the current through the voltage coil of the wattmeter at a relative large value for the low values of power which will increase the deflection of the wattmeter four to six times.

This year we hope to be able to keep the wattmeter on the line continuously. Tanks which have hitherto been used and require emptying or filling at intervals will be done away with. A nozzle will be used to spray the water to the ground from the upper end of the water column. It was found by test that a 6 ft. spray effected a complete break in current at 175 kv.

J. P. Jollyman (by letter): Mr Wilkins' paper is a noteworthy contribution to the knowledge of corona loss. The Pit transmission system offers an unusual opportunity to secure accurate data on the corona loss of three distinct configurations and two conductor materials.

The comparison of the results of the several methods of measurement employed is most interesting and clearly demonstrates the difficulties of high voltage measurements. The determination of generator output from the output of the prime mover is to be especially commended as a method of check. This confirmation of the accuracy of the readings taken on the low-voltage side of the step-up transformers gives great confidence in the results.

A study of the results of the tests as shown in Fig. 33 reveals some interesting information. The corona loss is found to be a function of the total applied voltage with a law of the form:

$$P = Ke^v$$

where P = KW corona loss
K = a constant
V = total voltage in kv.
e = naperian base.

For a given configuration K has a certain value up to a certain value of v which may be regarded as a "critical voltage." Above this value of v, K has a different value such that P increases more rapidly for a given increase in v. At a still higher value of v or possibly of P, K again changes and the increase of P for a given increase of v is less than in the preceding stage. This second change in the law marks the beginning of a voltage-wave distortion. This point was not reached on the aluminum conductor due to limitation of voltage which could be applied. Not enough data are available to determine with certainty whether the second point of change is determined by the total loss per mile or by total load on the generator. The indications are that the total loss per mile for a given configuration is the important factor.

Mr. Wilkins calls attention to a curious change in the corona loss of the aluminum conductor below the "critical voltage" not found with copper conductors.

The discovery that the measured corona loss on the Pit transmission followed exponential laws with exact precision led to a review of the data on the best available tests reported by Lewis, Faccioli and others. This study is shown in Fig. 40. Every curve but one follows exponential laws and this curve records the results of tests on a short sample. The tests made on the long lines where carried over a sufficient range of voltage exhibit the three stages of loss observed on the Pit tests.

The most important conclusions that can be reached from Mr. Wilkins' paper are:

1. Corona loss follows exponential laws both below and above the "critical voltage."

2. Factors not heretofore considered important, such as capacity to earth and configuration, have a marked effect on corona loss.

3. Aluminum has certain characteristics with respect to corona not possessed by copper.

4. Losses below the "critical voltage" are large enough to be of commercial importance.

5. Direct high-voltage measurements by methods heretofore employed are likely to contain errors due to phase angles and change in ratio, the correction of which are extremely difficult, if not impossible.

6. A new investigation of the subject of corona loss is required to establish the laws of corona loss within the commercial range. Such an investigation should be made on outdoor three-phase circuits of considerable length, so aranged that the configuration may be varied to conform with the several arrangements used in practise and transposed to give a complete barrel.

The commercial range of corona loss may be regarded as including corona losses from small values up to values about equal to the $I^2 R$ losses considered reasonable for a certain conductor. Under present-day costs, an increase in conductor size may be justified when corona loss exceeds one-quarter of the $I^2 R$ loss.

C. A. Jordan (by letter): It is merely the desire in this discussion to call attention to a fact which may be significant, but which appears to have escaped attention of Messrs. Ryan and Henline.

In Figs. 1 and 8 of this paper, it will be noticed that the longitudinal axes of the corona loops obtained with increasing voltage rotate about the origin with increasing angular displacement from the straight-line no-loss card as the applied voltage becomes higher. This denotes a gradual change in the voltage-charge relationship, and hence a change in the capacitance which determines that relationship.

It has been commonly, and apparently reasonably, supposed that ionization of the surrounding atmosphere increases the effective capacitance of a conductor. Unfortunately conclusive evidence on this point is not forthcoming from the paper under discussion. In Fig. 8, the axes of the corona-loss cards lead the straight-line no-loss card, indicating a decreasing capacitance with increasing loss. In Fig. 1, the axes of the corona-loss cards lag behind the zero-loss card, indicating an increasing capacitance. May it be supposed that the two sets of cards, made at times separated by an interval of years, were not obtained under the same conditions of instrument polarity, or that one set of cards has been incorrectly sketched for reproduction? If it be accepted that the effective capacitance of a conductor does increase with corona loss, some interesting conclusions are possible.

Referring now to Fig. 2, attention is invited to the loop axis, X-Y. The reciprocal of the slope on this line is the effective capacitance. The axis X-Y as drawn implies a constant capacitance, not only for all applied voltages, but for all values of the same applied voltage. If, however, the capacitance is increased by ionization, the axis cannot be a straight line. In this case (considering the first quadrant of the figure and starting with zero applied voltage) as the voltage is increased the conductor

charge will vary in linear relation, determined by the reciprocal of a constant capacitance, until the critical disruptive voltage is reached. At this point, capacitance will begin to increase and the slope of the axis to decrease by increasingly greater amounts until the crest value of applied voltage is reached. The same thing will occur in the third quadrant in the opposite sense, and the axis will then represent an elongated letter S, being concave downward in the first quadrant and concave upward in the third quadrant.

Having disintered the skeleton, may we attempt to construct the body? Such a skeleton immediately suggests the classical hysteresis loop teminating in sharp points. If this be the case and were it possible to determine for all physical, electrical and meteorological conditions the factors which determine the shape and size of the loop, it is probable that a relatively simple, exact law for corona would result. Undoubtedly Equation 2 of the paper is an approximation of such a law, but the equation seems subject to error through the use of a constant conductor capacitance.

It remains to reconcile the actual corona diagrams given in the paper and the familiar hysteresis loop surmised above. Two thoughts immediately come to mind: (1) Is the cathode-ray cyclograph capable of faithfully indicating or reproducing the instantaneous relations between voltage and charge? and (2) Do the diagrams indicate corona loss alone, or a combination of true corona and gaseous-conduction losses?

Picture a number of sharp-pointed hysteresis loops of increasing sizes, and possibly slightly different shapes, drawn about a common origin with sides generally parallel. Then consider the pointed ends rounded off as might be done by a lagging instrument. Are not the resulting diagrams similar in shape and inclination or rotation to those given in the paper, especially when it is remembered that the slope of the experimental loops is determined by the *average* capacitance?

Again, were test voltages carried to such high value that, in addition to corona, gaseous conduction occurred, the resulting cyclograph diagrams would be deformed from the pointed loop to an elliptical form, as is so well stated on Page 4 of the paper.

M. H. Gerry, Jr. (by letter): There is an important difference between conditions affecting the transmission of power and its distribution, although many of the problems are common to both. In many discussions of late there has been a tendency to confuse the two.

High-tension distribution is an economic necessity for the future, but it does not require voltages beyond the range of present practise. It involves delivery of power over an area and in practise functions through a network. Its problems are those of regulation, continuity of service and commercial efficiency.

Actual transmission of power is a distance problem and involves the transfer of energy in quantity from its source to a far removed center of distribution. Its further extension requires the employment of higher voltage.

Consider now, the transmission of power as the problem of transferring a large block of power a distance of say, a thousand miles. Can this be done commercially, and if so, how? At the present time power is being transmitted about three hundred miles, which appears to be near the distance limitations for sixty cycle three-phase current at the voltages now permissible.

A great forward step in the art is required if there is to be a material extension of the distance of power transmission, and only in this way will it be possible to make available in the centers of population the vast undeveloped water power resources of the nation.

The papers presented at this meeting go to the heart of the problem. Engineers must employ higher voltages for transmission but in what form or how applied we do not know. One important step is a clearer understanding of the nature of corona losses and another is their quantitative determination. Such losses must be suppressed or reduced to a small amount before progress is possible in this direction.

The study by Professors Ryan and Henline of the hysteresis character of corona is not only a contribution to knowledge and a clear experimental demonstration of certain facts, but it points the way to still more important fields of investigation and should give the engineering profession courage to believe that the limitations of voltage as applied to the transmission of power has not yet been reached.

Harris J. Ryan: Replying to Mr. Peek: In our studies of corona losses occurring from power transmission lines so far, we have fond only "per cycle" losses. Succeeding *half-cycle* losses are not independent but parts of the total loss per corresponding cycle. We are partly but not altogether in agreement that the corona loss is due to the collapse of the air as a dielectric adjacent to the conductors. In our understanding the loss occurs in reversing the charges on the free ions that surround the conductors in approaching and receding from voltage crests that are higher than corresponding critical voltage. The charge between opposing groups of ions is automatically limited to equality with the increase of charge between the conductors due to increase of applied voltage from critical to crest values. The *ion-attached charges* must be reversed in passing each voltage crest. The energies stored in such charges are not reactive as is the case for *conductor-attached charges*, and must all be degraded to heat, *i. e.*, molecular friction. This is the understanding that led to the derivation of equation (2) in our paper. In his discussion of Professor Harding's corona paper Mr. Carroll has shown that this equation and the corona loss-voltage relations found therein are in excellent agreement.

Corona, when existing on actual power lines is known to consist in few or many individual brushes, as the case may be. We have called attention to the hysteresis character of corona formation for a better understanding of brush formation and the loss of power therein. Our endeavor has been to accomplish a better understanding of the corona loss-voltage relations for power transmission lines when the losses are below 7.5 kw. per conductor-mile, or thereabouts. That is the range in which our equation (2) does not apply because therein the brush pattern is not fixed. We regard equation (2) as a criterion for fixing the corona-loss limits, below which, brush patterns are unstable.

In continuous-voltage corona formation the ions of like signs that are driven forth from a charged conductor meet and combine with corresponding ions carrying unlike charges driven forth from the oppositely charged return conductor. This is conduction by convection. Manifestly, the frequency can be lowered and the distance between the conductors lessened in alternating-voltage corona formation until conduction by convection also occurs. Physicists have determined in conduction by convection that, for an air-density factor of unity, negative and positive ions travel 1.83 and 1.35 centimeters per second in an electric field due to one volt per centimeter. The restricted conditions for which alternating-voltage corona will produce loss by convection may, therefore, be calculated.

Professor Sorenson's photographic studies are yielding helpful results. Years ago in an effort to observe the E–Q relation in the glass dielectric of a plate condenser fitted with tin-foil electrodes, the corona at the edges of the tin foil on the opposite faces of the glass plate yielded well defined hysteresis loops. The study of similar phenomena photographically must surely add to our understanding of the differing behavior of the free positive and negative ions in determining the hysteresis character of corona.

Mr. Hillebrand helpfully calls attention to the importance of knowing the carrying capacities of liquid films that will lead to an understanding of the problem of surface leakage over insulators. The high-voltage wattmeter is sufficiently sensitive and accurate for the promulgation of such studies.

Dr. Whitehead has contributed a number of helpful criticisms

and suggestions with most of which we are in hearty accord. Formerly we shared the views of Peek and himself that "We must increase the voltage above the initial loss value before we get to the region subject to definite law. We must reach a voltage whereat the irregular point discharges unite in increasing the diameter of the conductor and making it equivalent to a smooth conductor." Our understanding is that "the region subject to definite law" is due to the formation of a stabilized brush pattern and not that "the irregular point discharges unite in increasing the diameter of the conductor and making it equivalent to a smooth conductor." Mr. Jollyman points out that "under present-day costs an increase in conductor size may be justified when conductor loss exceeds one quarter of the I^2 R loss. Such loss occurs entirely within the *unstable-brush-pattern range*." Ardent study of the corona loss-voltage relation occurring in unstable brush patterns must, therefore, continue. As Mr. Wood states, these data are wanted because "they pertain precisely to that region on the voltage curve wherein we most probably will have to work for economic reasons." The unstable-brush-pattern losses are related to the total line voltages. We are convinced that law and order exist among them, though the factors are many and too little is known about them as yet.

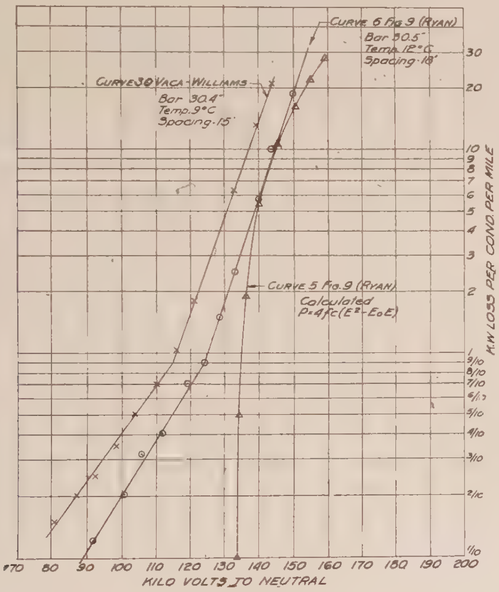


FIG. 13

When the corona losses have increased sufficiently to sustain stable brush patterns in clear weather their values vary much as do squares of the crest voltages in excess of the corresponding critical crest voltage. We cannot, however, conceive of the effective use of engineering constants or factors by which to derive unstable brush-pattern losses from the corresponding losses due to stable brush patterns formed at higher voltages.

Magnetic hysteresis is due to the presence of definite quota of molecular magnets left stranded in their polar orientation by atomic friction that cause alternating flux to lag with respect ot the corresponding alternating m. m. f. These residual molecular magnets are reversed as each flux crest is passed with a corresponding loss of energy. In a strikingly similar manner when 60-cycle electric fields of ionizing strength are set up in air, residuals of ions are left about the conductors that cause the electric field also to lag by definite amounts with respect to their corresponding e. m. f. s. Such stranded ions have their charges reversed as each voltage crest is passed. The energy stored in placing these charges about the conductors must be degraded to heat through molecular impact (friction) when by recombination and replacement their charges have been reversed.

Mr. Jordan notes the gradual rotation of the longitudinal axes of the corona loops with increasing voltage and concludes that such effect is due to a corresponding change in capacitance. This use of the term capacitance is apt to be misleading. Ca-

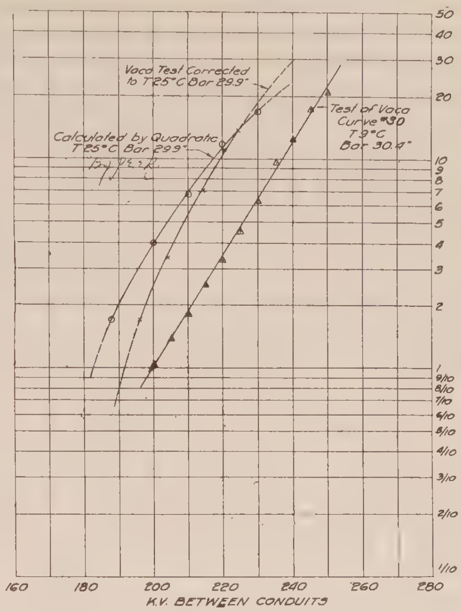


FIG. 14

pacitance of a conductor is the quantity or charge it accepts per volt. The quantities recorded in the cyclograms in excess of the corresponding conductor charges were employed in setting up the space charges on the free ions left by the corona between voltage

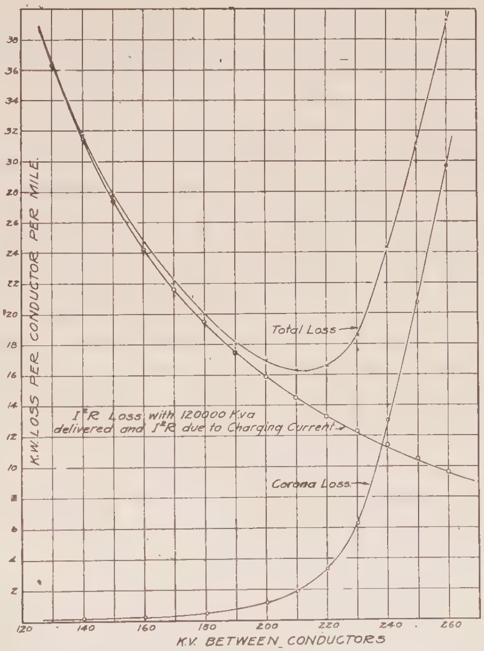


FIG. 15

crests. Conductor capacity is not altered in value by the presence of such space charges. In the course of our work many of the highly reasonable conjectures of the character brought forward by Mr. Jordan were also encountered. It would, however, have made our paper too long to have included a record of them and what we did in their regard. Equation (2) was the result of a

large amount of study beyond that of the make-up of the voltage-charge diagrams.

R. Wilkins: Fig. 13 herewith shows Prof. Ryan's Curve No. 6, Fig. 9 plotted on semi-logarithmic paper, together with a curve from the data of the test on the Vaca-Williams section of the Pit line at approximately the same temperature and barometer and a spacing of 15 ft. All of this section of the line had an elevation of less than 1000 ft.

There is also his calculated Curve No. 5, of Fig. 9, and I would point out that at 127,000 volts to ground we are running on a part of the curve which does not check.

By reference to Dr. Steinmetz, it seems necessary for comparison, to plot the curve in such a manner that the test data will form a straight line or a series of straight lines. Fig. 14 herewith shows this same test curve No. 30 with the temperature and barometer as indicated under constant weather conditions and taken at an altitude of less than 1000 ft. plotted on semi-logarithmic paper giving a straight line. There is also plotted a calculated quadratic curve for these conditions and also the curve shown by Mr. Peek of a correction of this test to a temperature of 25 deg. cent. and a barometer of 29.9 inches. By using a correction developed for a quadratic curve on the test data an entirely different character of curve is developed. It would seem more accurate to calculate the curve for test conditions.

Fig. 15 bears out the statement made in the paper that it is not economical to run below the corona point at least on this particular line. There is a decided minimum to the loss curve for a given kw. transmitted.

In closing, I will say that for values of corona loss on 300-ft. sections of the rope-lay cable taken in two of this country's best high-tension laboratories before the line was erected the variation from the test values taken on the Pit line in place at the operating voltage was somewhat over 500 per cent and the errors were in different directions. Any such variations in losses having a value of $100,000 per year is worth further study.

It seems worth while to make a plea for tests under practical operating conditions because as higher voltages and longer lines are used, it means dollars to the ultimate consumer.

Discussion at Midwinter Convention

THE SINGLE-PHASE INDUCTION MOTOR[1]

(Perkins)

New York, N. Y., February 9, 1925

V. Karapetoff: The problem treated by the author is quite old, and a complete absence of correlation with the work of previous investigators is rather deplorable. Thus, the whole set of papers and a voluminous discussion before the Institute in 1918 are entirely ignored, as well as the subsequent contributions to the theory of this class of machines. In 1921 I showed the equivalence of the two theories of the single-phase induction machine Journal, Vol. 40, page 640) and gave a new equivalent diagram, only one branch of which contains variable slip. A circular locus and a general-performance equation follow from this diagram directly. In Vol. 41 of the Transactions there is a paper by Mr. Kostko which to me only shows that elementary mathematics is inadequate to lead to a simple theory of the machine, on the basis of two oppositely revolving fields. Mr. Perkins' paper shows that elementary mathematics is also inadequate in the cross-field theory. I hope, therefore, that this method of approach will now be definitely abandoned in favor of more advanced and shorter mathematical tools. In the Journal for 1923 (Vol. 42, page 1181) I indicated the use of the scalar product of vectors in the solution of problems on locus diagrams of electrical machinery. This new use of vector analysis has already proved to be quite fruitful in a derivation of the exact circle diagram of the polyphase induction motor, without inversion or long formulas. The next step is to try this method on the single-phase machine, preferably using the unified equivalent diagram mentioned above.

Instead of a laborious step-by-step method, we ought to be able to write at once a few vectorial equations which represent all the essential relationships in the machine. For a solution of these simultaneous equations an advanced mathematical method (or some mechanical device) should be used, leaving the physical relationships "transparent" to the end. Of course, in numerical computations there will be products of complex quantities to evaluate, but there already are a few computing devices for a convenient handling of complex quantities, and probably in a few years computations with such quantities will be not nearly so tedious as they are now.

W. B. Hall: I have found considerable confusion existing in the minds of students and engineers concerning the fundamental analytical reasoning employed in the cross-field analysis of the single-phase induction motor.

1. A. I. E. E. Journal, Vol. XLIV, May, p.499.

We are accustomed to consider a conductor, or circuit. We determine the voltage generated in this conductor, the resistance and reactance of its circuit, and we say that the current lags the voltage by an amount determined by the ratio of resistance to reactance, or we may consider the reactance as a voltage, and determine the net voltage acting in the circuit. The current flow will then be in phase with this net voltage, which is the $I\ R$ drop.

In analysis of polyphase motors we sometimes use these methods of thought. We consider the voltage induced in conductor d. We say that the current will flow later, because of the reactance of the circuit, *and that d will then be in some other position*, where e or f were at first. This same attack may be applied to the single-phase motor. But it leads to unnecessary complexity.

So in single-phase-motor analysis another method of attack is used, as in this paper, but this new method has never to my knowledge, been clearly and definitely described. It has been rather assumed without distinct description, resulting in much confusion of thought on the part of many readers.

The new idea, which needs to be clearly stated, is that E_3 is not the voltage in any one conductor. If we plotted the value of the voltage in each successive conductor as it passd through the position d, we should obtain a sine wave, for ϕ_2 varies thus with time. A vector, E_3, may obviously be used to represent this sine wave, but it must be constantly kept in mind that E_3 does not represent the voltage in any one conductor, but represents the successive values of the voltage in each conductor as it passes through the position d.

Our usual ideas of reactance and resistance will not longer apply, since we have no circuit, but a succession of circuits. Hence Mr. Perkins abandons the idea of reactance and uses the method of determining the net voltage and considering that the instantaneous current flow in any of the successive circuits is directly proportional to the instantaneous value of this net voltage, which is the $I\,R$ drop at the successive instants of passing through position d.

Thus, in Fig. 4, E_3 represents the successive values of voltage in the rotor conductors due to cutting ϕ_2 at the instant that each passes through position d. E_6 represents the successive values of transformer voltage due to ϕ_c at the instant that each conductor passes through position d. I_3 is *not* the current in a coil d or in any coil, but represents the successive values of the current in each conductor as it passes through position d.

With this distinction clearly in mind some erroneous conclu-

sions may be avoided, and some hazy conceptions made clearer.

P. L. Alger (by letter): Mr. Perkins has given a very complete description of a circle-diagram method of calculation for single-phase motors, based upon the cross-field theory. The clear inference is that he considers this method and this theory preferable to their alternatives, the equivalent-circuit method and the revolving-field theory. It is my opinion that the second method is greatly preferable to the first, and that the latter theory is more accurate than the former.

The equivalent-circuit method seems preferable because it avoids the time consumption and the errors of graphical construction; it permits the constants of the motor to be varied to take account of saturation, eddy currents, or heating without duplication of the work; it affords a clear visualization of the fundamental application of Kirchoff's laws for the electric circuits to the motor; and it permits the study of the motor to be carried to any degree of approximation or of refinement without change in the method. Two advantages are generally claimed for the circle diagram method, that it avoids the use of vector algebra and that it permits an easy visualization of the variation of motor characteristics with speed. The first advantage appears rather to be a handicap, as it avoids the use of a very convenient and simple means of calculation in a place where it is most fitted for use. The second advantage is an important one, but it is obtained at the expense of another sort of visualization which may be equally satisfactory. It is generally true in the history of mathematics that graphical methods are developed first, but are later supplanted by abstract calculational methods as familiarity with the work is acquired and the need for increased accuracy and decreased time consumption becomes important.

The cross-field theory is, according to all the books, precisely equivalent to the revolving-field theory, so that any result may be obtained by either method. This equivalence of the two theories was again brought out by Mr. Kimball and myself in our recent paper on "Torque Pulsations of Single-Phase Motors," A. I. E. E. JOURNAL, December 1924, page 1142, when we derived the same formulas for the double-frequency torque by the two methods independently. However, there is one phenomenon, that of eddy currents in the squirrel-cage winding, that can be better taken into account by the revolving-field theory. If a double squirrel-cage winding, or its equivalent is employed, the secondary resistance is much higher at double, line frequency than at slip frequency. Thus, different values of secondary resistance must be used for the forward and backward field currents in the revolving-field theory. But in the cross-field theory, the secondary current in either axis is considered as a whole, instead of being divided into its slip frequency and double-frequency components. Thus, the resistances used in the secondary circuits of the cross-field theory must be intermediate between the high and the low value, but just what values they should have is a problem that has not been solved. In short no method has been published of properly taking into account eddy currents in the secondary by the cross-field theory, and so in this respect the revolving-field theory is superior.

L. M. Perkins: Professor Karapetoff brought up a very desirable feature: that we use as few operations as possible in deriving our vector diagrams. But he is pointing toward Utopia, I think, on account of the difficulty of making direct analysis without use of step-by-step methods.

One point which Prof. Karapetoff brought up is that he secures by his method a single variable, which variable is of course the slip. In the single-phase induction motor this variable is slip $\times$ (2 — slip) which comes out in this paper as well as in the oppositely-rotating field theory, the slip being, of course, the slip with reference to the forward rotating field, and the (2 — slip being the slip with reference to the oppositely rotating field.

In Fig. 21 of my paper there is a diagram showing the counter e. m. f., E_4' and the e. m. f. generated in the secondary conductors by the net flux, which is E_2. If from E_4' a line is drawn perpendicular to E_4' until it intersects E_2, the intercept between this line and E_2 (that is, the end of the vector) will be the length of this variable, $s\ (2 - s)$. If this is carried through, you will find that in the final diagram the circle having the one variable s and $(2 - s)$ is the one shown.

Another point brought up was the question of considering the rotor conductor as stationary. If you want to find what the current is in the rotor as it turns, there is no better method than using the oppositely rotating fields, but if you want to know what the primary input is, what power factor you will get for a given load (since the primary is stationary and the only way the primary can transfer energy to the secondary is by a stationary field), it is best also to consider the secondary as stationary, taking care of the effects of rotation by considering the counter generated by rotation.

A good illustration of the trouble that you get into when you consider the rotating-field method is apparent when you wish to determine the effect of increasing the reactance of the secondary winding. According to the rotating-field method, there are two separate currents in the secondary winding, one of slip frequency and one of $(2 - s)$ frequency. But what happens if you increase the reactance as far as it affects the slip frequency? There is no large change, but according to the normal way of looking at it, the current of the $(2 - s)$ frequency would be cut out almost entirely. It is rather hard to see how the performance is really affected, unless you follow this method, which shows that all currents in the rotor are really of line frequency and that, therefore, an increase in reactance of the secondary will cut down or will affect all rotor currents; the slip frequency current, as well as the $(2 - s)$ frequency current due to the oppositely rotating field.

The original purpose of this paper was to bring out the theory of the single-phase induction motor in such a way that the average engineer could follow it, although of course it is still very complicated. There are no assumptions as are necessary when you consider the oppositely-rotating-field theory.

TEMPERATURE ERRORS IN INDUCTION WATTHOUR METERS[1] (KINNARD AND FAUS)

NEW YORK, N. Y., FEBRUARY 12, 1925

H. B. Brooks: The paper by Kinnard and Faus is important and valuable, not only for its definite data and clear reasoning, but also because it is a tangible indication of the interest which is being taken in the question of the accuracy of metering. This interest reveals itself in many ways; for example, in the increasing attention which is being given to the ratio and phase-angle performance of instrument transformers. Among reasons for this interest may be mentioned the greater attention which must be given to plant operation, because of higher costs of fuel and other essential supplies; the growing tendency toward interconnection, with the consequent need of accurately measuring interchanged energy; and the necessity for accurate electrical measurements in acceptance tests of turbo-generator units, where an error of a fraction of one per cent may mean an error of thousands of dollars in penalty or bonus. Such tests must necessarily extend over a period of hours, and the load cannot be kept as constant as might be done with small machines in the laboratory. It is only natural, therefore, that those having to make such tests should turn to the watthour meter as a means of measuring the energy and hence the electrical power output. However, from information which has come to us, it appears that such use of watthour meters does not give results as consistent as can be had by the use of indicating wattmeters read at sufficiently frequent intervals. Nevertheless, the large amount of labor required for the latter procedure makes it desirable to bring up the performance of the watthour meter, if possible, to such a stage that it will be good enough for plant acceptance

1. A. I. E. E. JOURNAL, Vol. XLIV, March, p 241.

tests. The work done by Kinnard and Faus is an important step in this direction, and I hope they will continue their analysis of sources of meter errors and means for overcoming them.

There is an astonishing lack of accurate information on temperature errors in watthour meters. Published papers exist, but they either relate to meters of obsolete types, or lack necessary data. For example, one paper on temperature errors of American watthour meters leaves it to be inferred that the meters were of the alternating-current type, and while giving many curves of performance, fail to state the power factor of the loads. Text books also are often at fault; for example, an English book published in 1923 states that "In an induction meter both the operating and the braking torques are developed by the medium of eddy currents, often in the self-same disk, so that temperature effects cancel out completely." Similar inaccurate and superficial statements may be found in some other reputable treatises on meters.

Taking up the paper in detail, I would first inquire why a watthour meter was used as a standard by which to determine the performance of the meter under examination. Even though this standard meter was kept at room temperature, it seems probable that errors resulting from self heating and consequent temperature inequalities within the standard meter might affect the observed results undesirably, and that a wattmeter would have been preferable.

Referring to the tests at unity power factor with the lag plate removed, I would suggest that by replacing the lag plate with a lag *coil* of similar form, closed through an adjustable external rheostat, the effect of change of resistance could be readily determined.

A comparison of Fig. 6, Curve *C*, with Fig. 7, Curve *C*, shows that the high temperature coefficient of the copper lag plate is responsible for a fair share of the Class 2 error in this particular type of meter, and suggests the use of some material of lower temperature coefficient.

It is gratifying to have a definite answer, such as the authors give us, in regard to the idea that the length of the gap of meter magnets varies with temperature. The value given for the temperature coefficient of the gap flux presumably refers to the kind of steel in regular use at this time. Fitch and Huber, at the Bureau of Standards, found values ranging from -0.0001 to -0.0003 per deg. cent., with a mean value of -0.0002. At the time this work was done (1913) tungsten steel was used, as far as we were aware.

I think the authors are to be congratulated on their neat and simple solution of the matter of Class 1 errors, especially in view of the peculiar form of Curve *A*, Fig. 1, which they take care of by using two bridge pieces of different grades of thermalloy in parallel.

The statement that Class 2 errors are more prominent in two-element polyphase meters is evidently made with the idea that such meters usually measure loads of power factors less than unity, for on the usual assumption of a balanced three-phase load a polyphase meter working under a given phase-angle error (alike in the two elements) measures the total load on it with exactly the same error as would occur in measuring the load with an otherwise identical single-phase meter with the same phase-angle error. In other words, with balanced loads we do not need to reason differently concerning polyphase meters and single-phase meters as regards either Class 1 or Class 2 errors.

The next step is evidently to get rid of Class 2 errors, and if possible in a manner as simple and elegant as the one given in the paper for Class 1 errors. I wish to mention a method which has occurred to me recently, which has apparently been shown to be sound in principle by a simple experiment. According to Schmiedel, the flux Φ_I from the current electromagnet lags behind the current *I* (see Fig. 10B) by a small angle, which we may call γ, and which for simplicity the authors of the paper have not considered; the effect of this angle is that the lag plate must be adjusted to lag the voltage flux Φ_E by an angle δ which is not equal to ψ but to $\psi + \gamma$, at standard temperature. When the temperature increases, ψ increases while δ decreases, so that the compensation is no longer correct. In this lies the entire reason for Class 2 errors. I propose that we put a lag coil on the current electromagnet, thus lagging its flux Φ_I by an additional angle which may be called β. Hence at standard temperature we must now adjust δ to be equal to $\psi + \gamma + \beta$, in order that the meter may be correctly lagged. Let us give the lag coil on the current electromagnet a high temperature coefficient, for example by closing it through a resistor of very pure iron wire, and also give the lag coil on the voltage electromagnet a suitably low temperature coefficient. We may thus make the small angle β decrease with temperature at a sufficiently rapid rate to compensate for the increase in ψ and the decrease in δ; in other words, to maintain the relation

$$\delta = \psi + \gamma + \beta$$

at all temperatures, and thus eliminate Class 2 errors. It is obvious that β must also compensate for any change of γ, concerning which at present no numerical data seem to be available. It is of interest to note that the iron-wire resistor for the current lag coil may be embedded, whollly or in part, in the voltage winding, in order to respond to changes in temperature of the latter, just as the authors of the paper did with their carbon filament.

In making this suggestion, I realize that we cannot lose sight of the variables other than temperature to which a meter is exposed, such as variations of voltage, frequency, and wave form, and if my proposal for eliminating Class 2 errors should lead to an unavoidable increase in the errors from these causes, another and unobjectionable solution must be found. The suggestion is offered for what it is worth, in the hope that it may assist in the eventual solution of the problem of temperature compensation of watthour meters.

J. R. Craighead: With respect to Mr. Kinnard's paper, there is only one point I should like to call attention to. Under Conclusions, he has a conclusion referring to driving torque and damping torque as being only one side of the thing which may cause the watthour meter to go wrong. It seems to me that if the driving torque and the damping torque, in the broad sense, are both correct, you have a correct watthour meter. In other words, errors in driving torque or damping torque constitute the whole error. I would suggest that he use the word "flux" perhaps instead of "torque" in that place as expressing more accurately what he means.

F. B. Magalhaes: I wish to place on record a statement which is not intended to be complimentary on a personal basis to the authors but which would be made quite impersonally to any one presenting the same development. Progress in any field can be considered as going forward by more or less slow steps, and after a step forward has been taken there is a consequent search or analysis made on that step, to develop all of the possibilities that may be obtained from the single step forward.

The authors of this paper in using the methods which they have described have introduced a new means for correcting certain errors that have to the present time been considered more or less accepted or inherent in the design of a watthour meter. Without any doubt, this step forward will therefore be followed by a considerable amount of lateral or parallel research to develop all the possibilities that the step forward may offer. On this basis, it should be recorded that the idea of using a small piece of alloy near the jaws of the magnet as an automatic means for correcting the temperature errors that have heretofore had to be accepted, is distinctly to be commended as an important step forward.

One specific question I would like to ask is in reference to the permanence of the alloys which they have used. They have outlined in some detail the necessity of watching carefully the mixture of the alloy and their heat treatment. It leaves,

therefore, a question in the reader's mind, I believe, as to the ultimate permanency of the alloy. The results that have been obtained can be seen on the curves. However, the permanent value of the results that have been obtained will be based largely on the permanence of the correction that has been made. If the alloy is not a stable alloy and may change with the passing of time or under temperature conditions that may be encountered in the field, it will detract very greatly from the value of the results obtained. It would be interesting to know, therefore, what results the authors may have to establish this point of permanence.

Joseph Slepian: There are just a few consequences of the phenomenon that Messrs. Kinnard and Faus use that I think will be interesting.

Some time ago there was a patent issued to Thomas A. Edison disclosing the rather ambitious project of making a heat engine using this very phenomenon. Edison proposed to allow a large mass of iron to be pulled into a magnetic field, there to be heated until it became non-magnetic, and then to be released, thus getting work at the expense of heat energy.

The fact that it is possible to get work out of this phenomenon at the expense of heat makes it possible to apply the principles of thermodynamics and get relations connecting the properties of these materials.

One need only apply the first and second laws of thermodynamics. It will necessarily follow that a piece of magnetic material having a temperature coefficient must change its temperature as it moves from a weak field into a strong field. That is, its specific heat must change. I believe it will have to rise in temperature as it moves into a strong field and fall in temperature as it moves into a weak field.

I would like to ask Messrs. Kinnard and Faus just what are the special merits of the alloys which they have chosen. There are, of course, many allows that have transition points at temperatures in the ordinary range. Some of them have been known for a long time. Those of most interest were the Heusler alloys which contain no elements which are ordinarily magnetic, and the question occurs to me as to whether these other materials are wholly unusable, or whether it is simply some point of refinement that causes one to use these particular alloys rather than the others that are known.

W. H. Pratt: The method of correcting for Class 1 errors is peculiarly direct and effective. It corrects the errors where they occur and when they occur. I mean by this that the thermalloy shunt is in such intimate contact with the controlling magnets that it partakes uniformly of the temperature changes of the latter, and on account of the absence of hysteresis renders the correction particularly effective.

The course suggested for minimizing Class 2 errors is also directly aimed at securing excellent results, for by the reduction of the resistance of the potential coils not only is the desired result obtained, but it is a change that is in the right direction to improve still further the behavior of the meter in regard to frequency and wave-form errors.

I think this last remark has a bearing on some points that Mr. Brooks raised in his discussion. The arrangement that he proposed for compensating for phase displacement is such as to expose the windings to the rather extreme changes of temperature which comes from the current coils. The coils which he suggested would be naturally exposed to these rather extreme changes, and it would not accomplish that further refinement of the meter that is accomplished by a reduction in resistance.

C. M. Jansky (by letter): This paper is of considerable scientific and practical importance as it is the best analysis of the influence of temperature that I have seen. There is no mention made, however, of the study of this problem that was made at the University of Wisconsin several years ago by Mr. B. E. Miller. The results of his investigations of the effect of temperature on the registration of watthour meters at 10, 50, 100 and 150 per cent loads were published in the September 18, 1915 issue of the *Electrical World*. Mr. Miller's results show that the error is not the same with increasing as with decreasing temperatures. The per cent of registration when plotted against temperature gave a decided "hysteretic" loop. Messrs. Kinnard and Faus do not refer to this paper, but if they have seen it I would be pleased to have their explanation of this difference in the accuracy with increasing and decreasing temperatures.

I. F. Kinnard: In Dr. Brooks' discussion, he asked why we made use of a watthour meter rather than a wattmeter in obtaining our readings. We believe a watthour meter may be advantageously used as a standard, in order to study the effects of varying temperatures on another watthour meter if care is taken to insure that the standard watthour meter is kept at a constant ambient temperature, and if, before readings are made, it is allowed to run a sufficient length of time to reach its maximum self-heating value. Very accurate results are obtainable, with a minimum of trouble due to other possible variations such as frequency.

In connection with the point raised in regard to studying the effects of changes in temperature of the lag plate by the use of a lag coil with an external resistance, this can undoubtedly be done and should give interesting information, although for our particular purposes we did not consider it necessary. We do not feel that the lag plate causes temperature errors of sufficient magnitude to call for the use of brass or manganin as the situation now stands. It has been pointed out, however, in the paper that for certain applications Class 2 errors can and should be eliminated, or at least reduced by modifications of the potential element. When this is done the copper lag plate will undoubtedly be dispensed with.

It is true, as pointed out by Dr. Brooks, that the same reasoning applies to polyphase meters as discussed for single-phase. Class 2 errors are, however, of more importance in the polyphase meter due to the fact that the line power factor is frequently quite low. This can be fairly satisfactorily taken care of by using but one compensated and one uncompensated magnet on a two-element meter. As I previously stated (and it has been brought out in the discussion), the better way is to eliminate Class 2 errors by reducing resistance of the potential winding.

Mr. Magalhaes raises the question of the permanency of thermalloy used as a magnetic shunt. I wish to say that we have had magnets compensated in this manner under observation for over a year and a half and no aging effects of any magnitude have been observed.

We might also bring to your attention the fact that copper-nickel alloys have been continuously used for a large number of years in connection with resistance materials, Monel metal and other applications, and it is known to be a stable combination.

Mr. Craighead points out a statement in the first part of the conclusions that might be open to some question, and I believe his point is well taken. I meant to refer to the driving flux in classifying the errors that do not depend upon power factor.

Dr. Slepian points out a very interesting fact, that there are other alloys such as the Heusler alloys, which probably have some characteristics similar to those we have described for the copper-nickel series. As a matter of fact, we have mentioned in the paper that the Heusler alloys have a possible application in this connection, although we believe the copper-nickel series can be better controlled, has a somewgat higher permeability, and is easier to machine, outside of the fact that it is of lower cost.

Prof. Jansky asked whether or not there is a hysteresis lag in the heating and cooling curves of a watthour meter. We have not observed any such effect, in the large number of tests made with these meters, although there is a distinct time lag. That is, if a watthour meter is held at any one temperature for a sufficient length of time to reach equilibrium, its cooling curve will be identical with its heating curve.

THE THEORY OF PROBABILITY AND SOME APPLICATIONS TO ENGINEERING PROBLEMS[1]

(MOLINA)

NEW YORK, N. Y., FEBRUARY 12, 1925

B. Jones: In the introduction to his paper Mr. Molina draws attention to the apparently little recognized value of the Calculus of Probabilities in engineering studies. Permit me to draw your attention to the extraordinary importance this calculus has acquired in modern mathematical physics as a means of developing the necessarily statistical expressions for the so-called laws of nature.

Since the time of Laplace the calculus of probabilities has been the foundation of Astronomical research. It is the basis of the kinetic theory of gases. Maxwell shared with Gibbs the work of developing dynamics as a statistical science. As Reiche puts it "Planck has turned the problem of radiation into a problem of probabilities." Eddington points out that Einstein's grand summary is to the effect that "the present state of the world is that which is statistically the most probable." Thus, a branch of mathematical science born in a gambling dive, is found capable of dealing with the most varied classes of more or less random phenomena which, from craps to atomic structure, make up the detail of this world. It assumes nothing as fixed given or absolute, and, insofar, the formulas of probabilities are very descriptive of the world's behavior. Perhaps our's *is* the most probable world.[2]

Mr. Molina has given us an outline of a few important theorems in the probability calculus. I wish to present the outline of a further very elementary and very useful method of dealing with the probable character of a sample drawn from a mixture when the probable frequencies of the several components of the mixture are known, and when we are interested in the failure of the sample to be thoroughly representative of the mixture. The nethod has wide engineering application extending from the sampling of crushings, screenings, and concrete mixtures, to the determination of probable duty cycles as a means of selecting apparatus having suitable characteristics. It may also be used to determine the demand factor imposed on hydraulic and electrical distributing systems serving a number of devices operating intermittently, or subjected to varying demands.[3]

Let the total number of elements composing the mixture be P, of which one element has the frequency a, a second element has the frequency b, a third element has the frequency c, and so on. That is, $P = a + b + c + \ldots\ldots$

Let n be the number of different kinds of elements in the mixture, irrespective of the number of elements of each kind.

Let a sample having a total of N elements be drawn.

Then the probability that any one of these elements is an a, is a/P; that it is a b is b/P; that it is a c, is c/P; etc.

The probability that any one of these elements is not an a, is $1 - a/P$; that is it not a b, is $1 - b/P$; that it is not a c, is $1 - c/P$; etc.

The probability that none of the N elements drawn is an a is $(1 - a/P)^N$; and, so on, for the other kinds. Therefore the average probability that any element in the sample *will not* be any one of the n kinds is

$$1/n \left\{ (1 - a/P)^N + (1 - b/P)^N + \ldots\ldots \right\} \quad (1)$$

This is also the probability that the sample will not be representative of the mixture.

The probability that the sample will be representative of the mixture is

$$1 - \left[\frac{1}{n} \left\{ (1 - a/P)^N + (1 - b/P)^N + \ldots\ldots \right\} \right] \quad (2)$$

Therefore the probable number of kinds of elements contained in any sample of N elements is given by

$$S = n \left(1 - \left[\frac{1}{n} \left\{ (1 - a/P)^N + (1 - b/P)^N + \ldots \right\} \right] \right) \quad (3)$$

Should the sample be so constrained that any one element, say the p^{th} is certainly present, the corresponding term $(1 - p/P)^N$ is to be omitted from (1), giving, in place of (3),

$$S_{(n-1)} = (n - 1) \left(1 - \left[\frac{1}{n-1} \left\{ (1 - a/P)^N + (1 - b/P)^N + \ldots \right\} \right] \right) \quad (4)$$

as the probable number of different kinds of elements *other than* p contained in the sample.

Should it happen that all the elements are equally distributed in the original mixture, so that $a = b = c = \ldots\ldots = P/n$ where, as before, $P = a + b + c + \ldots\ldots$, and n is the number of kinds of elements in the mixture, then (3) reduces to

$$S = n \left\{ 1 - (1 - 1/n)^N \right\}, \quad (5)$$

a well known form that may be used in many cases where a b, c, etc., are not materially different from one another.

As a case, let it be required to find the probable number of stops that will be made by an elevator car containing N passengers drawn from a crowd of P people composed of a people bound for the first floor above the bottom terminal stop, b people bound for the second floor, c people bound for the third floor, ... , and x people bound for the top or nth floor.

Since, barring accidents, the top terminal or nth floor is a certain stop, the term $(1 - x/P)^N$ is to be omitted from (1) and the probable number of intermediate stops is given by (4). The total number of stops, including the top terminal, is $S_{n-1} + 1 = S$.

If H be the travel between the bottom terminal and the top terminal, the average distance covered between start and stop is H/S. From this, and the time-velocity characteristics of the equipment, the probable average duty cycle of the hoisting equipment can be determined, which, when converted to equivalent r. m. s. input, gives the equivalent continuous output.

If a number of such equipments are operating simultaneously, the probability method given in my paper on "A Method of Determining Resultant Input from Individual Duty Cycles" (JOURNAL A. I. E. E., May 1922) may be used to determine the equivalent continuous rating of the feeders to the hoisting-engine group. In spite of the fact that this paper has been characterized as "school-boy mathematics," the method has been in successful use for a number of years and has resulted in considerable savings in cost of installation, and particularly so in just such cases to which it has been said the method is inapplicable.

The most probable time distribution of load on generating plants has been determined by this method and given to manufacturers as a basis for the submission of apparatus suited both in type and rating to meet such probable actual conditions and not suited to wholly non-existent conditions resulting from purely empirical guesses. In recent cases we have found that the resulting temperature rise of the apparatus in service is extraordinarily close to the expected rise, indicating that the actual r. m. s. value of the load is fairly close to the calculated r. m. s. value, and that the owner has paid for machines neither too small nor too large. I have many records of cases where generating capacity and rated motor output, both determined on a wholly empirical basis, are considerably in excess of the actual demand—in some cases this excess is 50 per cent and more. Feeder sizes often run 100 per cent above the actual necessary rating.

In closing I wish to draw attention to the fact that the method of probabilities does not start from any pre-conceived mathematical notions from which, by purely logical processes and almost mechanical dexterity in the manipulation of mathematical

1. A. I. E. E. JOURNAL, Vol. XLIV, February, p. 122.

2. The Most Probable World, Jones, *Tech. Engineering News*, Vol. IV, No. 9, March, 1924.

3. The application of the method to the determination of water supply and waste in buildings is given in a Bureau of Standards *Bulletin*.

symbols in accordance with fixed rules, an answer is turned out willy-nilly. On the other hand, the method of probabilities is one of continuous cut and try based on no evidence other than the given data. It is no substitute for thought, but rather requires very clear reasoning at all stages of the process. Every step must be carefully visualized. This is its extraordinary advantage as a mental training. It has somewhat the same pedagogical value as the study of legal procedures. The correctness of the results obtained are wholly dependent on the common sense used in its application.

A. G. Chapman: Applications of the theory of probability have long been useful to telephone engineers in studying the problem of limiting crosstalk between telephone circuits to tolerable amounts. In considering crosstalk, two paralleling telephone circuits may be conveniently divided into a succession of short finite elements. The two circuits will be coupled in each element. The coupling is usually due to electric and magnetic induction, although in the case of a phantom circuit and its side circuits, resistance coupling may be of some importance. The speech power at a terminal of the disturbed circuit depends upon the resultant effect of all these couplings and upon the power impressed upon the disturbing circuit. In a well designed telephone plant the couplings are due to small deviations from perfect construction rather than to dissymetries in design. It is impossible, therefore, to predict accurately the crosstalk between any two well designed and maintained telephone circuits. Estimates may be made, however, of the most probable crosstalk between two circuits and the chance of exceeding the most probable value by various percentages. In case there are a number of circuit combinations having the same probability of a given value of crosstalk, it is useful to estimate the average crosstalk and also a value of crosstalk which there is but a small chance of exceeding.

Such estimates are very useful in studying the importance of deviations from perfect construction in loading coils, in sections of telephone cable and in any apparatus occurring repeatedly in a long telephone circuit. Estimates of probable crosstalk are also essential in studying the design of loading systems and systems of arranging repeaters in telephone circuits as well as in considering the matter of permissible deviations from the theoretical values in the spacing of wires and transposition poles of open-wire lines.

The computations of probable values of crosstalk must, of course, be coordinated with an extensive program of testing to serve as a check on the necessary approximations in the computations and as an indication that the circuits have been installed in the proper manner.

As a formal mathematical problem, applications of the theory of probability to computations of crosstalk offer considerable difficulty and the solutions are necessarily approximate. The problem involves determining the probable resultant of a large number of deviations, that is, the successive couplings between the elements of the telephone circuits. The law followed by the individual deviations must be approximately determined from experimental data. It is usually satisfactory to assume the normal law of error for the individual deviations but the law of combination of the various deviations is usually complex. Two adjacent deviations of the same magnitudes may not add or subtract algebraically since the resultant crosstalk currents of any particular frequency may be out of phase due to a difference in the nature of the two couplings. In long telephone circuits, the attenuation of the speech waves and the finite speed of propagation with its resultant retarding of phase must be taken into consideration, and also the large number of frequencies of which a speech wave may be assumed to be composed. As a result of the propagation phenomena, two similar but non-adjacent deviations will produce crosstalk currents at a circuit terminal differing in phase and magnitude, depending upon the distance between them and the frequency. In addition, the separation between two telephone circuits may not be uniform. For example, in a telephone cable, two circuits may be adjacent for a short distance, say 500 ft., and then occupy a large number of non-adjacent positions before coming together again. In spite of all these complexities, however, it has been found practicable to obtain approximate solutions of probability crosstalk problems which have been very useful in engineering the telephone plant.

R. S. Hoyt: Mr. Molina has chosen his principle illustrative examples from the extenisve field of traffic and trunking problems.

I believe that the Institute will be interested at this time in an outline of applications of probability theory to certain problems in two other fields of telephone engineering—namely, in telephone transmission engineering, and in radio engineering.

Of the three problems which I propose now to outline, the first two arose in the applications of two-way telephone repeaters to long telephone lines or cables, and the third relates to the use of selective circuits for reducing "static" interference in radio reception.

By way of preface to the first two problems it may be recalled from the theory of repeaters that the practicable amplification obtainable from a two-way repeater is limited by impedance unbalance between the two lines involved, or between the two lines and their balancing networks. The theory of probability finds here a natural field of application because the impedance unbalance mentioned arises mainly, or at least to a considerable extent, from numerous random internal irregularities in the structure of the lines, as will appear more fully in the following outlines of the two problems themselves.

The first problem relates to periodically loaded lines or cables. These contain numerous small random irregularities consisting in slight inequalities in the inductances and spacings of the loading coils. The individual departures are effectively unknown; but their arithmetic averages are known from coil manufacturing data and line construction data, and the probability laws to which they conform are known or else can be reasonably assumed. For such a loaded line, when already constructed, the problem is to calculate the probability that the line has an impedance departure less than a specified value. On the other hand, in the designing of such a loaded line, the probability problem is to predetermine the allowable average coil-inductance departures and spacing departures to meet the requirement consisting in a specified probability that the impedance departure will not exceed a specified value. Such problems arose as long ago as the construction of the first transcontinental telephone line.

The second problem relates to continuously loaded cables. Such a cable may comprise numerous short sections which are slightly unequal in their linear constants, owing to manufacturing variations. If these sections are connected in a random sequence the probability problems are analogous to those outlined in the preceding example. On the other hand, from a study of the measured constants of the individual sections it is possible to determine the best sequence of the sections to minimize the resultant impedance departure of the final cable. However, the securing of this optimum sequence involves additional expense besides delay. To decide whether these are justified, probability may be invoked in order to determine the probable impedance departure that would result if the sections were connected in a mere random sequence. Such a problem arose several years ago in the design and construction of the submarine cable between Key West and Havana.

The two problems just outlined illustrate the fact that in a physical system so extensive as the Bell System there exists many classes of numerous physical elements such that the elements in any one class, while all nominally alike, actually differ from each other by small random amounts in a statistical manner. Usually it is impracticable to know the numerous departures individually, and, even if they were known, it would usually be impracticable

to compute their resultant effects of direct summation. But from the mere knowledge of a statistical index (such as the arithmetic average, for instance) and the statistical or probability law to which the departures conform, the probable departure of the system can often be calculated with relatively little labor.

The third problem, which is quite different from the two preceding, arises in radio transmission, and relates to the possibilities and limitations of selective circuits when employed for reducing "static" interference. Owing to the unknown, irregular, and random character of this type of interference, the problem is essentially a statistical and probability problem leading to an expression of results in terms of mean values. Such a treatment has yielded general deductions having practical significance, notwithstanding the meagerness of knowledge regarding the character and the frequency-distribution of static. Reference may be made to a paper by John R. Carson entitled "Selective Circuits and Static Interference" which was presented to the June meeting of this Institute in Chicago. (A. I. E. E. JOURNAL, December 1925, page 1145).

TESTING HIGH-TENSION IMPREGNATED-PAPER-INSULATED, LEAD-COVERED CABLES[1]

(LEE)

NEW YORK, N. Y., FEBRUARY 10, 1925

D. W. Roper: The paper by Mr. Lee (the best discussion of the subject of testing high-voltage cable that has ever been presented to the Institute) contains a great amount of interesting information all drawn from the experience of one cable manufacturer. Some of the conclusions which he draws are, therefore, rather limited in their application as they refer solely to the particular type of insulation with which he is familiar. As will appear later in this discussion, there is a wide variation in the characteristics or properties of the insulation made by the different manufacturers. For the purpose of broadening our view and thus improving our perspective, and not for the purpose of making any invidious comparisons between the products of the several manufacturers, I am going to quote some of the results that we have obtained in testing the product of a number of cable manufacturers, in the hope that I may be able to show how some of the conclusions given by Mr. Lee should be modified.

On the eleventh page of his paper, Mr. Lee cites the case of the failure of an experimental length of cable connected to a 110-kv. three-phase overhead line, and states that the examination revealed absolutely no discernible cause for the failure.

About one-third of our failures in service result in a similar manner.

In another paragraph on the same page, the author states that the study of the current-time curves obtained with insulation-resistance measurements should be vigorously continued. On this point I thoroughly agree with him and offer him our continued assistance and bespeak for him the cooperation of other operating engineers who are in a position to assist. The development of additional methods of testing cable should result in the discovery of causes of failure for which no explanation can now be given.

In Fig. 1 of the paper is given some data regarding the variation in insulation resistance of fourteen reels of cable, the maximum range being of the order of 10 to 1. A study of our records shows that in three shipments of similar cable ranging from thirty to sixty lengths, the maximum range in insulation resistance was 1.6 to 1 as compared with Mr. Lee's figure of 10 to 1 for fourteen reels. The author thinks that such measurements are of little value as a means of distinguishing between good and poor cable. In view of the data regarding other makes of cable which have been quoted, it appears that the results given by the author indicate that in his factory they have not secured control of all of the factors which affect the quality of their insulation. It also appears that studies made for the purpose of eliminating the present variations in insulation resistance will result in methods that will bring about an improvement in the product, and that there is an even greater chance of such a result than that the studies of current-time curves of insulation resistance will result in the discovery of improved methods of testing.

1. A. I. E. E. JOURNAL, Vol. XLIV, February, p. 156.

No methods of testing high-voltage cable will be satisfactory until it is possible to detect and reject at the factory all cable which contains the germ of a failure which will occur shortly after the cable is placed in service, such as the example cited by the author. This requirement, while it may appear somewhat idealistic, becomes more important as the operating voltage of the cable is increased. On a 12-kv. line we may be able to carry a maximum load of 8000 kv-a.; on a 33-kv. line, this figure will be about 15,000 or 20,000 kv-a.; on a 66-kv. single-conductor line, the load may be 40,000 or 50,000 kv-a.; and on a 110,000-kv. single-conductor line, the maximum load may be 70,000 kv-a. These figures. which are illustrative, and not intended to be strictly accurate, show that the importance of continuous service inceases rapidly with the operating voltage.

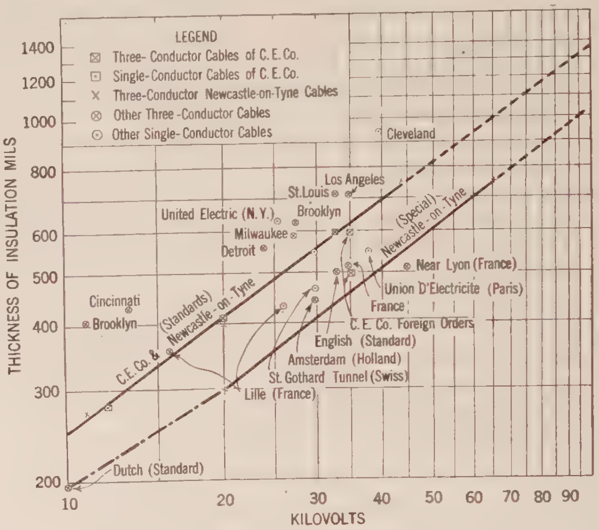


FIG. 1—RELATION BETWEEN THICKNESS OF INSULATION AND OPERATING VOLTAGE

The record of a number of recent installations of high-voltage cable made in this country and abroad, as shown in Fig. 1 herewith indicates the general trend of thickness of insulation as related to the operating voltage. This record indicates that the operating voltage is increasing at a faster rate than the thickness of insulation. This means that as the operating voltage increases the dielectric stresses increase, and if the cable is to be as successful in operation as cable of the lower voltages, there must be a continuous improvement in the quality with the increase in the operating voltage. It is therefore quite necessary, as stated by the author at the beginning of his paper, that improvements in cable manufacture should be paralleled by improved methods or additional methods of testing, so that we may be able to distinguish good cable from cable that will prove unsatisfactory in service.

The rainbow that the engineers of some manufacturers, as well as engineers of operating companies, including the speaker, have been chasing for a number of years is the search for some single test that will discriminate between good and poor cable. But impregnated-paper insulation is such a complex structure and as made at different factories has such wide variations in its several properties, that the discovery of any single test that will prove adequate seems to be just as hopeless as the discovery of perpetual motion. Impregnated-paper insulation has a number of

different qualities, as set forth by the author, such as insulation resistance, dielectric strength, dielectric loss, etc., and these qualities are so interrelated that it is difficult, or perhaps impossible, to improve the insulation in one particular, without having some effect on the other qualities, and these several qualities

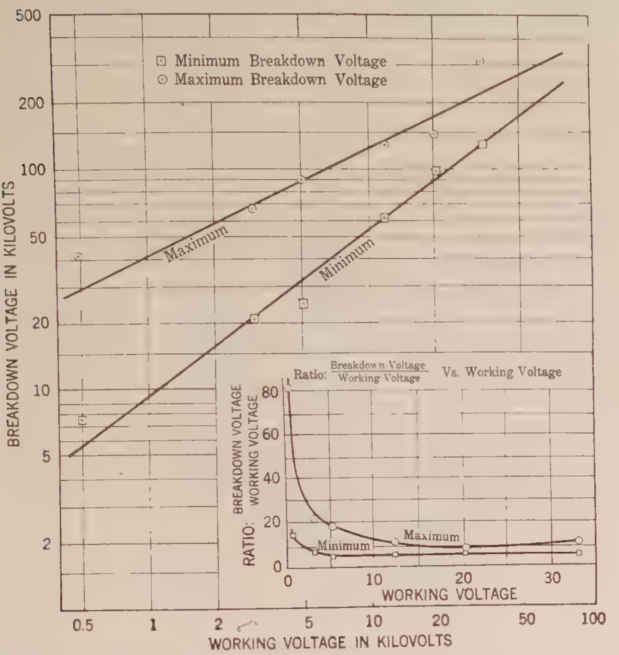


Fig. 2—Breakdown Voltages of Tests on Hot Straight Samples of Impregnated Paper Insulated, Lead Covered Cables

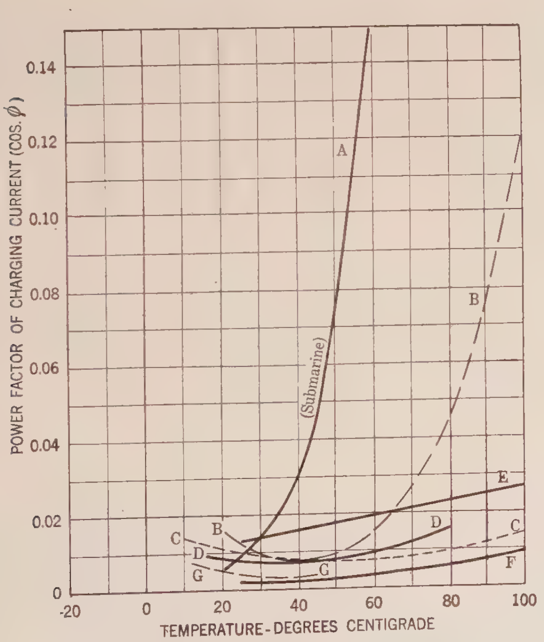


Fig. 3—Variation of Power Factor with Temperature for High Voltage Cables

Curves *B*, *C* and *D* are guarantees. Curves *A*, *E*, *F* and *G* are of test results. All curves are for 60 cycles except *A* and *C*, which are for 50 cycles

individually have very different values in determining whether the cable will prove successful in service.

In Fig. 2 herewith are shown the maximum and minimum dielectric strength values obtained in accordance with A. I. E. E. Standards on short lengths of cable for all of the sizes purchased by the company with which the speaker is connected, during the last two years. All of these cables have met the requirements of the N. E. L. A. Specifications and the A. I. E. E. Standards. It will be noted that the range in dielectric strength varies from 5 to 1 for low voltage cables to about 1.5 to 1 for 20-kv. single-conductor cable, and 2.4 to 1 for 33-kv. cable. It appears fairly evident from these data that the several cable manufacturers place very different weights on the importance of dielectric strength.

In Fig. 3 are shown a number of curves showing the variation of dielectric loss with temperature which are typical of the product of practically all the leading cable manufacturers in the world, each one of whom thinks that in this particular feature his cable is entirely satisfactory. With such wide variation in the forms of the curves and in the values of the losses at the maximum operating temperatures, it does not appear that all of them can be right.

Fig. 4 shows in a similar manner typical ionization curves; that is, the variation of power factor with voltage. One manu-

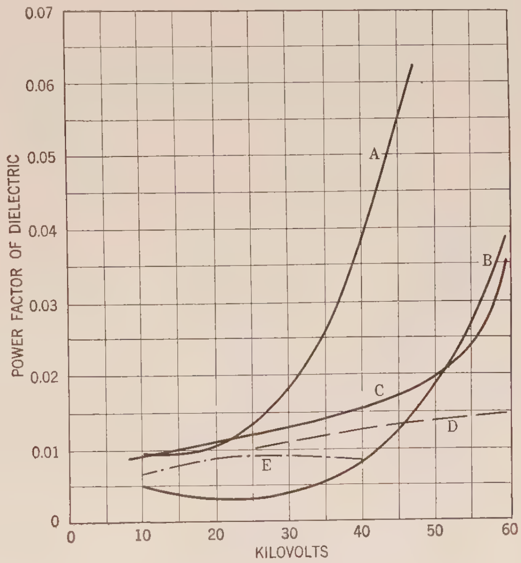


Fig. 4—Ionization Tests on Three Conductor High-Tension Cables

All 33-kv. cables except *D*, a 10-kv. cable

facturer contends that there should be no variation in the power factor between 50 per cent and 150 per cent of normal voltage, while another manufacturer contends with equal force that a variation of 2 per cent over about the same range of voltage is permissible. No one manufacturer makes cable which is the best in all of those qualities described by the author which collectively indicate it excellence, and, in the face of such conflicting statements presented by the various cable manufacturers that are equally skillful and reputable, what is the purchaser to do?

During recent years, improvements in cable manufacture have been so rapid that it is not possible for an operating company to buy cable of several different combinations of the qualities illustrated, and then wait for five or ten years to determine from operating experience which of the several varieties is the best before purchasing any more cable. Commercial developments and increases in load compel the operating companies to buy cable every year, and even if they should wait for five or ten years before buying more cable, they would then be told by the manufacturers that such cable was no longer made, due to their improvements in manufacture and cable of a different combination of qualities would be offered.

Table I shows the writer's suggestion for a solution of this problem. In it are listed all of the test requirements given by the author. There are also given in the third column under the heading *Weight for Best Performance* the writer's judgment as to the relative weight which should be assigned to each of those qualities or properties. As set forth in the table, all of these cables comply with the N. E. L. A. Specifications and the A. I. E. E. Standards, but it will be noted that they pass the specifications with widely different margins in the various particulars. The cable which gives the best results in the ionization test is not the best in dielectric loss nor dielectric strength. As these figures in the column called *Weight for Best Performance* are the personal opinions of the writer, it is entirely possible that they are all wrong or that a different method of calculating the relative performance of the several manufacturers from the test records should be used. A number of similar tables have been calculated, using radically different figures in the column of *Weights for Best Performance.* These calculations show that changing the figures in this column to any other figures which appear to be within reason makes but slight changes in the relative order of the manufacturers.

manufacturers, and agree upon the particular quality or property of the cable whose deficiency was responsible for each failure, and from the mass of operating records of this kind which are available for study, modify not only the weights for best performance from time to time in accordance with operating experience, but also the minimum requirements of the specifications.

There is no country in the world in which the engineers of the manufacturing companies and those of the operating companies are so well organized as they are in America, through their technical associations, like the A. I. E. E., and the commercial associations like the N. E. L. A. and the A. E. I. C. to bring about such cooperation in a proper way. If this cooperation can be secured, there appears to be no good reason why the American cable manufacturers in a few years should not be leading the world in the manufacture of high voltage cable, instead of occupying their present subordinate position.

W. F. Davidson: Mr. Lee has presented a very helpful summary of the present status of testing high-tension paper-insulated cables so far as concerns tests to be made in advance of installation, but I feel that it is unfortunate that he does not have more information to present in regard to tests intended to determine the fitness of the cable to meet the requirements of continuous operation.

TABLE I

COMPARISON OF RESULTS OF INSPECTION AND TESTS ON 3-CONDUCTOR CABLE RATED AT ABOUT 13 KV. AND MADE IN 1924

All of these cables comply with the N. E. L. A. Specifications and the A. I. E. E. Standards

Item No.	Item	Weight for Best Performance	Weights for Various Manufacturers A	B	C	D	E	F	G
	Mechanical								
1	Wrinkles	4	4.0	3.2	3.0	3.0	4.0	2.8	3.6
2	Creases	4	4.0	3.0	3.6	3.0	3.6	3.2	3.6
3	Tearing in cold bent sample	4	3.2	4.0	3.0	3.6	3.2	3.0	2.9
4	Fillers	4	4.0	3.6	3.4	2.0	3.4	4.0	2.6
5	Impregnation	8	8.0	6.2	8.0	6.2	6.2	4.0	6.2
6	*Other conditions	6	6.0	4.8	6.0	3.8	4.8	3.3	3.9
	Electrical								
7	Range of insulation resistance	5	3.1	2.6	5.0	2.0	3.4	4.5	2.5
8	†Increase in Power Factor—Average	5	4.0	5.0	2.3	4.9	3.9	4.8	3.4
9	Increase in Power Factor—Maximum	10	7.9	8.1	4.7	9.0	5.6	10.0	7.1
10	Dielectric loss at 80 deg. cent.—Average	3	0.9	2.2	1.0	3.0	1.0	1.5	1.2
11	Dielectric loss at 80 deg. cent.—Maximum	7	2.1	4.6	3.1	7.0	3.4	3.6	3.4
	Puncture Voltage								
12	Hot straight sample—Average volts per mil	7	7.0	6.5	6.9	6.8	7.8	6.5	5.4
13	Hot straight sample—Minimum volts	11	8.6	7.8	8.4	7.4	11.0	9.3	8.1
14	Cold bent sample—Average volts per mil	8	8.0	6.9	6.7	6.7	4.2	3.0	4.1
15	Cold bent sample—Minimum volts	14	13.5	14.0	13.1	8.9	10.0	7.2	10.1
	Total weight, mechanical	30	29.2	24.8	27.0	21.6	25.2	20.3	22.8
	Total weight, electrical	70	55.1	57.7	51.2	55.7	50.3	50.4	45.3
	Grand total weight	100	84.3	82.5	78.2	77.3	75.5	70.7	68.1

*"Other conditions" include: (1) Twisting of sectors; (2) Registered tapes; (3) Workmanship in starting and ending tapes; (4) Thickness of lead and insulation in routine and deformation tests; (5) Overall diameter; (6) Condition of lead sheath.

†Increase in power factor at room temperature between 45 per cent and 215 per cent of rated voltage.

Date: February 5, 1925.

Such calculations indicate that the general method is correct; but some adjustment of the details may be necessary to secure greater accuracy. It is not pretended that the figures at the foot of the table correctly represent the relative merit of the cables on a percentage basis, but it appears that the table does determine, with reasonable accuracy, their relative order of merit.

It should be possible by a study of the test records and the operating records to determine with a fair degree of approximation the proper figures to be used for the weights for best performance, and after this has been done, the rating of the cables consists mainly of simple arithmetical calculations from the test records. After such a tentative assignment of weights has been agreed upon by the manufacturers and the operating companies, then the manufacturers have a definite statement of the desired combinations of qualities to guide them in the improvement of their product.

The operating companies, on their part, should carefully analyze all of their cable failures, with the assistance of the

The tendency to use higher test voltages and slightly longer times of application in tests on reel lengths and samples seems to be a step in the right direction, for it will tend to eliminate weak spots and it is always the weak spots that causes trouble. But there are many things which we cannot learn from short-time tests, or even from tests of several hours duration. Several operating companies using cables at the higher operating voltages have lately found signs of a slow but very noticeable deterioration. In many cases this has been accompanied by the formation of a substance variously known as "X", "wax," or "cheese." Efforts to produce this substance in the laboratory have generally been unsuccessful except where the time of test has been prolonged to many hours; short-time tests yield no results. This experience would seem to indicate the desirability of making tests on samples of cable using a voltage only slightly—say, 50 per cent—in excess of the rated voltage and then making

a thorough examination, including chemical tests, after two hundred or three hundred hours. There is another point, which may be touched on later, and that is the need for more elaborate tests to detect the presence of injurious impurities.

The data presented to show the significance of insulation-resistance values are certainly almost enough to lead one to discard them entirely from cable specifications. However, they seem to have a value which Mr. Lee has overlooked. The user

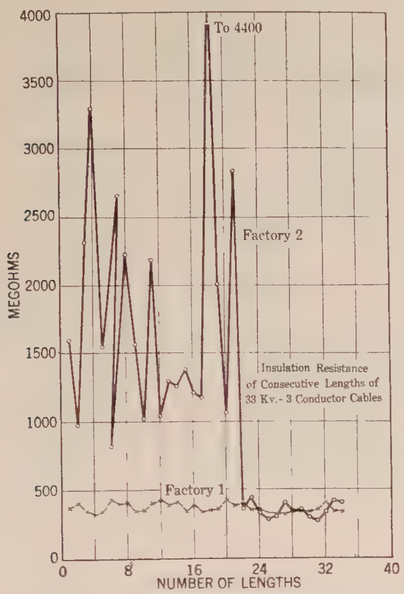


Fig. 5—Insulation Resistance of Consecutive Lengths of 33-Kv., Three-Conductor Cables

of cable is vitally interested in securing cable of uniform quality—999 ft. of superlatively good cable cannot keep a line going if 1 ft. is defective,—and it is my feeling that uniform cable will show reasonably uniform insulation resistance. When one stops to consider the very complex nature of cable insulation, it is not surprising that no simple relation has been found between insulation resistance and other characteristics of the insulation. But this does not, to my mind, afford a valid reason for rejecting them. As an example of that point in mind and illustrating what is commercially possible, I have plotted the insulation-resistance readings (see Fig. 5) on successive reel lengths of cable brought up for test in two factories. In one case the ratio of maximum to minimum values is about 1.32, while in the other case it reaches 15.6. These cables have not been in operation long enough to permit a statement to be made as to their operating performance, but it is interesting to note that the first lot of cable gave distinctly superior results on all of the other tests. As I see it, this means that the factory processes in the first case were more carefully controlled than in the second case.

Several curves are presented with the paper to show the relation between the test voltage and the time required to secure failure, but I feel that in their present form they are somewhat misleading. Take Fig. 10 as an example: We find that nearly instantaneous breakdown was secured with five variations of test voltage between 132 kv. and 100 kv. and we also note that 44 kv. produced failures in times varying from 30 hours to 160 hours. A curve has been drawn to pass through all of the points with remarkable precision. One might be led from this curve to assume that the cable would operate indefinitely at 43 kv. The experimental data seem rather too few for determining a curve and one would wish that figures were availalbe to show the life of the cable at, say, 30 kv.

Partial failures, such as are described, have long been known to those who have studied cable insulation and we find frequent reference to them in the technical literature. I think it is going a little too far to suggest that these failures generally occur near the center of the insulation. Undoubtedly they do occur, as Mr. Lee observes, at points where the insulation is unusually weak or where the stresses are high but this point may be quite as well near the conductor as at the center of the insulation. In a number of samples taken from cable of ten different makes, burns have been observed rather more frequently at the point of high stress—that is, at the surface of the conductor. For the obvious reason that the conductor is itself practically an equi-potential surface the tree designs are not found near the surface of the conductors but other forms of partial failure are very common.

Reference is made to the direct-current or kenotron testiing method outlined by Messrs. Phelps and Tanzer in a paper presented before this Institute. Where attempts have been made to apply this method to low-loss cables it has been the common experience that it was difficult to get satisfactory results. Some experience along this line with the Brooklyn Edison Company seems to indicate that the difficulties are very largely the result of the rapid decay of the charging current. Whereas the old cables tested in Philadelphia showed that from two to three minutes is required for the current to reach a fairly steady value, low-loss cables show steady current values after about ten seconds. This makes it impossible to rely upon readings taken visually but special high-speed curve-drawing instruments have been used with very satisfactory results.

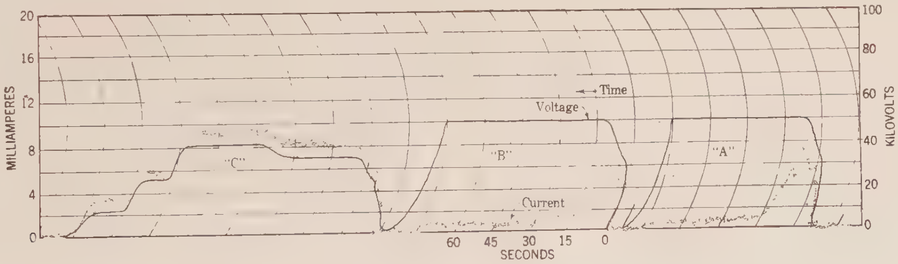


Fig. 6—Graphic Record of Kenotron on Cable Showing One Leaky Conductor

The illustrations shown here indicate the type of results which can be secured, although it must be admitted that the case chosen is somewhat extreme. Fig. 6 herewith shows a reproduction of the graphic millimeter record with the voltmeter record transferred to it as a solid line. It will be noted that A and B conductors behaved as good conductors should behave, while C conductor showed excessive leakage. Just previous to the test, this feeder had been tested at the normal value of 135,000 volts, direct-current conductor-to-conductor for five minutes and 95,000 volts, conductor-to-sheath for five minutes but, as indicated, even this high voltage had failed to remove all of the faults. Conductor A and B were grounded, and C conductor was raised to 98,000 volts and after five minutes failure occurred in a defective joint. When this had been removed the feeder was tested at 135,000 volts and 95,000 volts as before. Then the tests shown

in Fig. 7 were obtained. A few such cases as this seem to be ample justification for the use of this method. They also point to the moral that high voltages alone do not give sufficient assurance that a piece of cable on a complete feeder can operate at the rated voltage.

In passing it may be worth while mentioning that the kenotron test method offers real advantages in the nature of sizes of testing equipment and ease of testing. A test set designed for 200,000 volts from conductor to conductor with a 250-milliampere output has been built and mounted on a 6-ton motor trailer. It would be quite impossible to move about a-c. testing equipment capable of handling the same feeders. Moreover, experience in Brooklyn with comparatively high d-c. test voltages has failed to bring forth any evidence indicating damage to the cables as a result of repeated direct-current tests.

J. B. Whitehead: There is general agreement nowadays that insulation resistance based upon the one-minute observation is of questionable value. The reason is that insulation resistance has little bearing upon the loss and upon the performance of a cable, unless the resistance happens to be extremely low. In the latter case, however, one of the puncture tests would be certain to pick it up. The loss due to insulation resistance is a negligible part of the total loss of a normal cable, being of the order of 1 per cent or 2 per cent. The one-minute test is an indication of the dielectric absorption or residual charge of the cable. Taken at one minute this particular quantity has no special interest. If the rate of absorption could be measured for a small fraction of a second we should have important information. The loss in a dielectric is almost entirely due to absorption. It

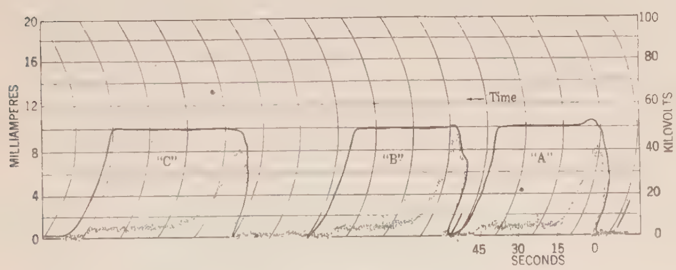


FIG. 7—RECORD OF KENOTRON TEST ON GOOD CABLE

would be very important if we could know the type of variation of the absorption during time intervals corresponding to fractions of the complete period of the alternating voltage. The laws of absorption are not sufficiently definite to enable us to deduce these values from the one minute test.

Will Mr. Lee please tell us whether the curves between the power factor and insulation resistance give the order in which the observations were taken? The curve for insulation resistance ascends continuously and if the points were taken in order it should be easy to trace the causes of the changes appearing. If these one-minute observations give the absorption it is easy to suggest two possible reasons for the differences shown. Absorption is most sensitive to the presence of moisture and also to temperature changes. A further factor often leading to erratic one-minute readings is the influence of the preceding state of the material. Small traces of residual charge will often cause wide variations in the one-minute reading.

Breakdown of cable insulation may be divided broadly into two types; direct puncture, and slow heating. The latter may begin as due to normal absorption loss, but ultimately it is a heating due to the passing of current. It seems to me that in the case of cables breakdown must fall into the second class. Cable insulation has pronounced absorptive qualities and this accounts for practically all of the initial losses. It is of immediate importance therefore, in determining a proper test for picking out as defective cable, to consider the test from the standpoint of its influence upon the internal losses. Thus, I believe that the high-voltage puncture test should not stretch beyond a comparatively short interval of time, as its chief function should be the picking out of flagrant imperfections. If a high puncture voltage is applied during a considerable length of time, an abnormal duty is imposed upon the insulation from the standpoint of heating, and increasing absorption due to temperature. The losses vary as the square of the voltage, and as even a higher power of the temperature. Two and one-half times normal voltage causes an *initial* rate of increase of loss of over six times normal. It seems to me therefore that the suggestion of the author to increase both the value and duration of the voltage test is open to serious question because of the extreme abnormal duty which may be imposed on the insulation.

I agree with the author that not too much importance is to be attached to the power-factor test. The power factor involves not only the loss but also the capacity of the cable. Both these quantities are variable and you may have a cable that is open to suspicion from the standpoint of loss, but which may not be defective as based upon the power-factor test. Naturally if the power factor is abnormally low it is a good indication of trouble.

I offer the suggestion therefore that the best method for testing cables as they come through the factory is the measurement of the loss, and to as high a degree as possible, the distribution of the loss along the length of the cable. I am quite conscious of the difficulties of such a plan but I believe that everyone will agree that cables ultimately fail due to increasing local losses. Fortunately however the rate of increase of these local losses is initially not very rapid. A measurement of the total loss on a length of cable may completely screen the presence of a dangerous local loss. The ideal test therefore would include not only the total loss test but a measurement of the time rate of change of temperature at intervals over the entire reel length.

R. W. Atkinson: I shall limit my remarks to the method of measuring dielectric loss by the a-c. bridge. My earliest work in cable engineering was in measuring dielectric losses by a bridge method. I have retained an enthusiastic interest in that general type of measurement of dielectric loss because of the very great advantages it has over many other methods.

The bridge Mr. Lee has described undoubtedly accomplishes in a very satisfactory manner the measurements for which he has used it. We have been using a bridge method that has a greater range of adaptability than Mr. Lee has apparently expected from his method, and I think it may be of interest to give a very brief description of that method and a rough comparison of the differences between the two. This may be done briefly, because our method has recently been published in the February issue of the *Electric Journal* (1925, p. 58).

I shall describe our bridge in terms of Mr. Lee's Fig. 17. The left-hand side of Mr. Lee's bridge is shown as a condenser, the cable, in series with a resistance R_3. The right-hand side of the bridge is the condenser C_2, and a resistance R_4 shunted by a variable condenser. In our bridge, the variable condenser C_4 is absent, and we have a variable resistance in series with C_2. This of course is the Wien bridge which has been used by many and which was described in a Bureau of Standards bulletin about 20 years ago.

In order to make it available for high voltage, we have made one important change. Fig. 17 shows the cable and the high-voltage condenser connected together and the junction point connected to the source of high voltage. In our bridge we have opened this junction; the high voltage is connected to the cable, and a low voltage is connected to the right-hand side of the bridge. This requires an additional low-voltage transformer on this side, and necessitates a compensation, the value of which is determined by means of a standard or zero-loss condenser which is connected across the high-tension side of the line at all times that the cable sample is connected thereto, and which is connected

in the bridge circuit in place of the unknown condenser by means fo a voltage-switching connection.

The general method of operating the bridge is to compensate by a special compensating circuit so that the loss is read correctly on the zero-loss condenser, the low-voltage switching connection is made, and the condenser or cable is then measured.

With the Wien bridge, the same voltage is connected to both halves of the bridge. If it is desired to use this method at high voltages, a great many difficulties are introduced because of the fact that the resistance in series with the condenser, C_2, is at high voltage. By opening the bridge and having high voltage on the cable only, these difficulties are avoided. With the Schering bridge described by Mr. Lee, some of these difficulties are avoided by eliminating the variable resistance at high voltage and using a variable condenser at low voltage as shown in Fig. 17.

I notice that Mr. Lee uses as much as 10,000 ohms in R_4. With the detecting circuit that we have, we are able to measure extremely small samples with a maximum resistance of 1000 ohms in the corresponding arm. If there is any capacity, as there usually is, between the right-hand corner of the bridge and ground, there will be an error in power factor, unless it is corrected, of exactly the same sort in either bridge, and of the same sort as the adjustment in power factor that is purposely made by Mr. Lee's condenser C_4. With 1000 ohms, which is the maximum resistance we use, that error is only 1/10 as much as it would be with 10,000 ohms. We have found it convenient and satisfactory to compensate for this error where it is desired to make accurate measurements. In general, the accuracy possible is to about 0.01 per cent in power factor. We often do not try to go this far, but it is quite possible even to exceed that degree of accuracy.

Another advantage of our arrangement over any other form of bridge that I have seen described is that it is suitable for the measurement of three-phase losses. The primary of one of our transformers is reversed in direction, and the bridge then becomes available in exactly the same way that a dynamometer-wattmeter is used in connection with the three-phase measurement of power factor of cables.

In conclusion, I would like to add that our resistances are independently variable, so that power-factor balance may be made without reference to the capacity balance which makes for a very wide range of adaptability of this method of measurement.

W. A. Del Mar: There are listed in Mr. Lee's paper five classes of tests, all of which are intended to indicate whether cable will be reliable in operation. These tests are all more or less accepted and standardized, in spite of the fact that no one can prove a very definite connection between most of them and the subsequent reliability of the cable.

Thus the insulation resistance test is known to be meaningless. The author has shown how an immense variation in the value of the insulation resistance occurs even in cable impregnated at the same time and in the same tank.

The factors which affect the insulation resistance of the cable are the resistivity of the oil, the resistivity of the paper, and the relative amounts of oil and paper.

Take the matter of the oil alone: The oil which is furnished to the cable manufacturers is a very small matter to the oil refiners. To them lubricating oils, etc., are the principal things. They do not, as a general thing, pay very much attention to the very exacting requirements of the cable manufacturers. The result is that in purchasing oil with a specified minimum resistivity, the variation in resistivity is likely to be very great, sometimes of the order of 100 to 1. There is a similar situation with regard to the paper, but it is not such a big factor as the oil. Of course, the ratio of oil to paper also depends somewhat upon the tightness of the paper and the perfection of impregnation.

Hence, there is really no reason why one should get a uniform resistivity, and I rather suspect that it never is obtained except at very low values. You will have noted, in Mr. Davidson's curves, that the manufacturer who showed a uniform resistivity had a uniformly low one, whereas the one who had variable resistivity was generally high, and at one time it came down to, but not below, the other. I should rather suspect that, in the case of the manufacturer who had the low resistivity, there was either some unknown leak in the testing circuit or improperly dried or over-oxidized oil which rendered all the values constant.

With regard to the dielectric-strength test, there is considerable misunderstanding about that, as is to be seen from the arguments about the direct-voltage proof test. Experiments have been made which show that cable tested with direct voltage has a tendency to break down at about 2.4 times the voltage that causes it to fail with alternating voltage. From this fact it is commonly deduced that proof tests with direct voltage should be 2.4 times the proof tests with alternating voltage. I do not think that this is a logical deduction because we are not interested so much in the conditions at breakdown, as we are in applying a test which will not initiate injury, and we are yet lacking in information as to the relative voltages, direct and alternating, which initiate deterioration.

The dielectric-loss test has been shown to be useful in distinguishing between two classes of cable, namely, those in which accumulative heating occurs at low temperature and at high temperature; it has, however, been rather generally assumed that because a cable with 5 per cent power factor is better than one with 20 per cent, therefore a cable with one per cent power factor is better than one with 5 per cent.

I do not think that we have been justified in being so enthusiastic about very low power factors. There are experimental reasons, substantiated to a certain extent, by practical experience which indicate that very low power factors may be dangerous because of the inability of the cables to absorb transients. When a transient gets loose on a line, if there is no place for it to be absorbed, it is likely to cause damage. This effect is of little importance at 13,000 volts, but becomes of increasing importance as greater voltages are used.

Some definite information on this was published by G. W. Partridge in the *Electrical Review*, 1924, vol. 94, page 992. Some of the old Ferranti cables were on the same system as some modern cables. The old cables having high dielectric losses, especially in the joints had quite an advantage over the low-loss cables in the small number of pressure rises which occurred, especially at times of light load.

The capacitance test is in the same class as the megohm test; it does not mean anything in relation to the value of the cable. It is one of the survivals from the old days of telegraph-cable engineering.

The last of the five tests listed is the bending test, which seems to me a way of passing the sins of the cable installer and designer onto the cable manufacturer. The bending test seems to be in the nature of a confession on the part of the operating companies. It has stood and still stands in the way of progress in high-voltage cable design.

What do we need to assure the permanent success of a cable? We need five things:

First, ability to carry the normal voltage.

Second, ability to carry or dissipate probable transient voltages.

Third, chemical stability.

Fourth, high temperature of accumulative heating.

Five, adequate but not excessive flexibility.

The first and fourth problems have been fairly well solved—ability to carry the normal voltage and the making of the temperature of accumulative heating high—but the other three have not been fully solved. American cable manufacturers ought to be given an opportunity to concentrate upon solving those problems instead of on trying to get uniformity in megohms, certain values of capacity, flexibility and other things which do not mean anything at all.

E. W. Davis: There can be no doubt that the standard acceptance tests as applied to low-tension paper cables are not a safe basis for determining the quality and performance of paper cable for the higher working voltages. For low-tension cables, the mechanical and physical tests of the insulating materials are often of equal if not greater importance than the electrical tests. But as we pass from low-voltage to high-voltage cables, and especially as we approach the high operating voltages of 33,000 and 66,000 volts, the results of electrical tests assume tremendous importance. By a relatively short-time test, we must be able to determine the suitability of a paper cable for long-time operation. At the present time, we have much to find out about the electrical properties of a finished cable and the relation of these properties to the electrical properties of the various materials that go into the construction of the cable.

It has often been found that paper and impregnating compounds which show the best results for mechanical and physical properties have the lowest values for electrical properties.

While the insulation resistance of a cable as it is measured at the present time may be of doubtful value, yet the fault may not be in the method of measurement, but rather one of interpretation. We have not as yet been successful in establishing any relation between d-c. resistivity and power factor. On the other hand, when we have had paper cables that showed insulation resistance values below normal, we have invariably found the cause either in materials used or processes through which the cable was put during manufacture.

Long-time high-voltage tests are undoubtedly a necessary part of acceptance tests of to-day, to determine the suitability of a cable for high-voltage operation. On the other hand, the length of time and the proper magnitude of the voltage are unknown quantities.

Standarization of testing apparatus, especially apparatus for making dielectric-loss and power-factor measurements, is a matter that should receive attention. All the present methods give fairly satisfactory and consistant results at the higher temperatures, but results at low temperature (20 deg. cent. and 40 deg. cent.) vary considerably with the kind of apparatus used to make the tests. The Schering bridge offers, perhaps, a satisfactory solution for this problem.

The question of high-voltage d-c. testing is still open to discussion. As in high-voltage a-c. testing, the question of the proper magnitude of the voltage is of vital importance. The speaker has in mind a cable system that apparently withstood an a-c. test of 30,000 volts but failed when retested on 25,000 volts d-c. No satisfactory explanation for this phenomena has been offered.

C. L. Dawes: Mr. Lee in connection with the description of the Schering bridge mentions a three-stage audio-frequency amplifier which increases the sensitivity of the detector to the necessary value. At Harvard University, in connection with research being conducted under the N. E. L. A. Paper Cable Research Committee, we have developed an amplifier almost identical in design to the one used by Mr. Lee. In view of several recent queries concerning the design and use of such amplifiers, Mr. Lee suggested that a description of such an amplifier might be of interest to the Institute at this time.

In some of our measurements we use a high-voltage bridge, two of whose arms have impedances of several megohms. For a detector we use a vibration galvanometer also of the iron-vane type, but unlike the one described by Mr. Lee, it has electromagnets and also it must be critically tuned. In order to function properly in our bridge the detector must have not only high power sensitivity but must also have a very high input impedance because of the high impedance of the bridge arms with which it is associated. We were unable to make the galvanometer itself fulfill these functions even when all the design factors were carried to the limit. Since the input impedance of a thermionic tube is very high, the use of such tubes in the detector circuit immediately suggested itself. Accordingly, a tube amplifier was designed and constructed, the details being worked out by Mr. G. H. Browning, a Research Fellow in Electrical Engineering.

At first, the amplifier consisted of seven stages but later as the galvanometer was improved the number was reduced to three. A diagram of the amplifier is shown in Fig. 8.

Owing to the low frequencies with which we work, it was found desirable to use resistance coupling between stages, rather than than transformer coupling. Special 102-D tubes were used for the two stages, since this type of tube has an amplification factor of 30 or 40, whereas the usual amplifier tube has an amplification factor of only 7 or 8.

In the last stage a 201-A or similar tube is used because its plate-circuit resistance is substantially equal to the highest transformer input impedance which it was practicable to construct. This transformer between the last tube and the galvanometer is necessary in order to reduce the transition loss between the tube and the galvanometer, the galvanometer impedance being only of the order of 1500 ohms at 60 cycles.

This amplifier theoretically gives an amplification of 3000, and rough tests have shown it actually to be approximately 1000. Although at first sight this amplifier appears simple, it was necessary to overcome many difficulties before it became practicable. Considerable experimenting was necessary to determine the proper relation between grid condenser and the resistance of the grid leak. The amplifier is very sensitive to magnetic and

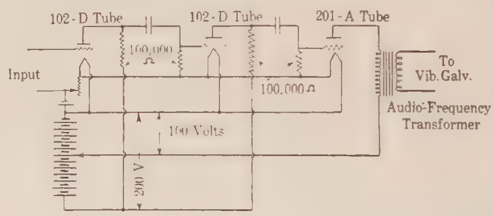


FIG. 8—AMPLIFIER FOR USE WITH GALVANOMETER

electrostatic fields and hence must be carefully shielded from both. The shielding must be sufficient distance from the tubes to prevent capacitive feed back. The input lead and the galvanometer lead must be twisted and surrounded by grounded sheaths, and yet the capacitance between these two sets of leads must be very low or feed back will result. With a high-impedance bridge, such as we use, it is absolutely necessary to bring the two input leads to ground potential, as otherwise capacitance e. m. fs. between these leads permit stray currents to flow in the bridge, resulting in a false balance.

C. F. Hanson: At the bottom of the ninth page of Mr. Lee's paper he makes the statement that three-phase power factor may be taken as the average of the power factor obtained with connection B at voltage E, and the power factor obtained with connection A at voltage $E/\sqrt{3}$. I wish to say that my experience confirms that statement.

At the bottom of the tenth page, Mr. Lee suggests that connections A and B in Fig. 20 be standardized. These connections require single-phase testing and consequently four different connections on the cable are necessary to obtain the power factor in various parts of the insulation. To make these four different connections consume a considerable amount of time. I should prefer three-phase testing because only one connection has to be made. The transfer of the measuring instruments from one phase to another can be done with properly designed air switches at ground potential. The time saved and the convenience gained is desired from a production point of view.

If the ground on the sheath, connection B, Fig. 20, is removed and the sheath, instead, is connected to the middle point of the high-tension winding of the testing transformer, the current

flowing in the wire connected to the lone conductor of the cable will be fairly accurately the three-phase charging current of the cable at voltage E. The three-phase dielectric power loss may accordingly be obtained with only one single-phase reading. Obviously, the lead sheath of the cable needs to be insulated from ground in order that the measuring instruments may be at ground potential.

James A. Duncan: I was very glad to note the remark made this morning by a cable manufacturer's representative to the effect that the manufacturers are now keeping an eye open to the possibility of impurities entering the cable in the oil used. I have in my hand a sample of paper given me as a fair representative piece of what had been put into a number of reels of cable made by a certain manufacturer for the Brooklyn Edison Company. This piece of paper has a resistance of less than an ohm and an average dielectric constant of infinity and a power factor which I have not measured, but which is probably somewhat execessive for so-called "insulation."

In this connection it seems well to consider some of the impurities which certainly exist in cable insulation and some of the reactions which are known to take place with such materials.

Ozone, for instance, causes a number of reactions to take place in hydrocarbon oil. Messrs. E. W. Blair, T. S. Wheeler, and W. Ledburry report in the September 1924 *Journal* of the Society of Chemical Industry an experiment in which ozone was bubbled through boiling normal saturated hexane. The formation of formaldehyde and acetaldehyde in relatively large quantities and of small amounts of water, carbon monoxide and carbon dioxide were definitely shown to result. Probably all the acids up to the hexoic and the hexyl hexoate ester are also formed.

It has long been known that certain metals catalyze the sludging process of mineral oils. Dr. Hans Staeger in the *Schweitz Elektrotechnischer Verein Bulletin* for March 1924 discusses the present state of our knowledge on this subject, including the very valuable part which his own experiments have contributed. He finds the presence of copper, brass, nickel, iron, zinc, tin, aluminum, lead, constantan and rheotan accelerate the acidulation of, and consequent sludge formation in, the oil. The magnitude of the effect varies, of course, with the metal and the time.

Four hundred per cent more sludge was formed in 1000 hours in a sample of oil in contact with copper than in a similar pure sample. The sludges usually consist of both soluble and insoluble (in oil) parts, and each of these parts may consist of both neutral and acid constituents. The oils oxidize the metals and in the case of copper, brass, zinc and lead actually partially dissolve them. Copper, zinc and lead have been detected in the sludges formed in the presence of these metals. The insoluble sludge with lead contained 20 per cent of the metal.

Both aluminum and iron have been detected in samples of the so-called "cheese" or wax formation found in three different cables. These impurities are easily traceable to the paper used in cable manufacture. The aluminum presumably goes into the paper in the form of alum, which is used as a size. I have detected it in five samples of paper, but failed to detect it in fibre just before it enters the last beating process in the paper manufacture.

The form or amount of aluminum in the "cheese" has not yet been determined. Samples of cable paper from every cable-paper mill and from every cable factory in the country have failed to produce so much as a square millimeter in which the presence of iron cannot be detected. The chemical test for iron is extremely sensitive and it is very possible that one might detect chemically iron occurring in such small quantities as to be of no importance.

To avoid making this mistake, I have also applied a physical test by means of a magnet.

It is astounding to me that the cable manufacturers are using "insulating" paper which contains pieces of iron of sufficiently large dimensions to be picked up with a magnet. I have several pieces of paper with such spots of iron in them that it is possible to ring a door bell in a battery circuit including two flat electrodes "insulated" from one another by the paper.

Aside from the conductivity of the iron, it is extremely objectionable for another reason. One could hardly imagine a better situation for the production of ionization than a region bespeckled with rough bits of metallic iron, unless it were bits of copper.

Suppose we think of a cable as consisting of a very large number of small unit lengths and think of each of these units as consisting of a condenser and a resistance in parallel. These units will then all be connected in parallel. If we admit that, for reasons outlined above or otherwise, one of these units may be very different from the average of the rest. Suppose, for example, its conductivity is very high and its capacity either high or low. It then becomes immediately obvious why one would not expect the average resistance and the average capacity, dielectric constant, or any quantity depending upon the capacity to bear any single relation to each other, for the reason that when in parallel capacities add arithmetically, while resistances add reciprocally. One very low resistance may be the predominant factor in a parallel connection, while a low capacity would offset the average for the set very slightly.

For example, in a cable supposedly divided into a thousand equal units, if one unit were altered so as to have one-thousandth the resistance and one-thousandth the capacity of its normal amount, the average capacity would be altered 0.1 per cent, while the average resistance as determined by measuring the whole cable would change approximately 50 per cent.

It seems to me, therefore, that the resistance ought to be one of our best tests because it can not be uniformly high unless every individual element of the cable is at least fairly high. In testing a length of cable in the ground power-factor measurements might not distinguish between a uniformly poor cable and one merely containing bad spots, while a kenetron test, for instance, will burn through the weakest element of a spotty cable.

Herman Halperin: On the third page of the paper it is stated that "the best samples of three-conductor cable for 33 kv. have a breakdown voltage on short-time tests of 200 kv." Three different makes of this kind of cable purchased by the Commonwealth Edison Company have had breakdown voltages of over 200 kv., and on one make the maximum voltage was 315 kv. In the latter case the average breakdown on about five random samples was almost 300 kv. between conductors. These data are quite different from the figure given by Mr. Lee.

The average gradient obtained in these samples was over 400 volts per mil on one sample and over 600 volts per mil on the other sample, which values are about double the value of 250 volts per mil given by Mr. Lee as being about the best obtainable.

The cable insulation is a very important part in potheads and even though we have trouble with failures in the crotch on samples, it appears to me that the voltages obtained by breakdowns in the potheads are an indication of the quality of the cable. For instance, in tests on seven makes of three-conductor, 33-kv. cable in Chicago and at the factories, we have found that old deteriorated 33-kv. cable might fail in the crotch at 125 kv., while better or new cables of the same make would fail at about 180 kv. Then the new samples of the three makes of 33-kv. cable previously mentioned withstood tests of over 200 or 300 kv., after which they had failures in the potheads.

The suggested increase of 20 per cent for full-reel high-voltage tests on three-conductor cables at the factory, seems to be insufficient. We have tested about twenty lengths of various makes of 200-ft. section of 12-kv. three-conductor cable and found that some cable which had been in service and failed due to defects in the cable, has withstood tests of 46 kv. for one, two, or three hours. These lengths had previously withstood factory tests of 30 kv. for five minutes. Increasing that factory test to 36 kv. would have easily allowed considerable unsatisfactory cable to pass the requirements. An increase of 50 per cent is more reasonable to insure satisfactory cable, but even then some

unsatisfactory cable might pass this test. It is for this reason that it is necessary to have the other tests in order that all the tests together will insure cable which will be satisfactory for operation.

For instance, as pointed out in his Figs. 19 and 23, which show the variation of power factor with voltage at room temperature, if the increase in power factor is small the cable is superior to "poor cable" which has the large increase in power factor shown in Fig. 23.

On the twelfth page a large number of factors are enumerated for the d-c. to a-c. ratio, and a conclusion is given that each individual case must be considered separately. This would result in a complicated set of formulas which would probably be impracticable. It appears to me that the ratio could be changed on the basis of some major considerations, such as temperature and thickness of insulation.

Apparently the ratio now being used, that is, 2.4, is conservatively low because Mr. Lee's tests show that the proper ratio is 3.0 for cable with insulation for 12-kv. service, and he states the ratio increased for larger thicknesses.

S. J. Rosch: The author describes for the object of his paper "an attempt to devise a method of testing high-voltage cable, which will determine its operating characteristics in advance of its installation."

In looking through this paper, I find a series of statements of present practise accompanied by a series of statements showing the results of certain tests made by the company with which the author is associated. I fail however to see any real constructive criticism as to what values should be used as criteria for the determination of the suitability of cable before it leaves the factory. I am not wholly in sympathy with the author's conclusions and the discussion I shall present, is an attempt to clarify some of the points which in my opinion the author's paper has failed to do.

Of all the mysteries presented to the electrical engineer for solution, the most baffling in my estimation has been the impregnated paper cable. It seems to me that the greatest cause for this mystery has been provided by the cable purchaser. To amplify this statement, let me say that the greatest cause for the lack of a proper understanding of cable phenomena has been the vast multitude of specifications supplied by various purchasers for high tension cable.

Take for example a cable for 13-kv. service. Specifications for this type of cable range from a wall of 9/64 in. on the conductors and 5/64 in. on the belt to 14/64 in. on the conductors and 8/64 in. on the belt. One can readily conceive that of two cables made of the same materials under the same routine, the cable with the heavier wall of insulation will certainly have the greater factor of safety. If therefore we start comparing the operating performance of 13-kv. cables of several utilities, we find ourselves comparing cables which should be alike, but which are absolutely foreign to each other.

Until the present time, the purchaser has been specifying every criterion for the determination of cable quality, but apparently the best of these specifications have been unable to pick out defective material. I believe it would be well to pause for a moment to see if we can trace some of the underlying causes for this fact. The testing of a cable generally consists of two phases, namely,

(a) Tests made on the full cable length.

(b) Tests made on a sample of this cable.

Right here in my opinion is the crux of the situation for there has been entirely too much testing of the samples, and not enough of the cables. Look through your N. E. L. A. reports or the proceedings of the A. I. E. E. and you will find that although cables intended for 33-kv. service have failed after only three months of service, nevertheless samples which were supposed to be representative of these cables, could not be broken down at 230,000 volts. Furthermore cables whose samples did not break down at these high values, are operating without any difficulty whatsoever. What inferences can we draw from the above? The ones that I would draw are as follows:

1. That the dielectric strength of a sample is not to be taken as indicative of the dielectric strength of the cable.

2. That there may exist a compound which has high initial values, but which deteriorates rapidly under actual service conditions.

3. That there may exist a compound which has moderate initial value, but which remains practically constant for a period of years.

If what I say be true, the solution must be obvious. The standards by which a cable is measured must be revised. In revising these standards, we must bear in mind that it is the cable and not the sample which is to be placed underground. We must therefore begin studying the cable more closely and look to the sample to give us only such additional information as cannot be revealed by the cable. I shall now take up the various tests in their order.

Full-Reel High-Voltage Test

Until such time as the thicknesses of insulation for various working voltages are standardized, I believe that the following test values should be used.

For cables up to 15 kv. the test voltage should be either 100 volts per mil or two and a half times the rated voltage, the larger of the two values being the one to be used for the test voltage. The voltage should be applied for five minutes. For cables rated at 16 kv. to 25 kv., the test voltage should be either 125 volts per mil or two and a half times the rated voltage, the larger of the two values being the one to be used. The voltage should be applied for five minutes. For cables rated at 26 kv. and over, the test voltage should be computed on the same basis as that prescribed for the 16- to 25-kv. class except that the period of application be fifteen minutes instead of five.

On cables rated above 15 kv. one reel out of every ten should receive an additional test of twice the working voltage applied for one hour. I consider all of the above tests as the best yet advocated for the determination of high-quality long-endurance cable. The values advanced are not high enough to overstress the insulation, and yet provide a very considergble factor of assurance that the cable will stand up under the rated service conditions. The last test, namely, the one applied for one hour to one out of every ten reels, is one of the most important in that it gives a fair idea of the endurance ability of the cable in general. Choosing one reel out of every ten, is almost the same as giving each reel an endurance test, since the reel selected, will practically represent the condition of each particular batch of cable as it is manufactured.

Insulation Resistance

The subject of insulation resistance has always been more or less of a joke in the paper-insulated cable industry. Every attempt at some form of standardized specification has recognized this fact in one way or another. In the Report of the Underground Systems Committee of the N. E. L. A. of 1922, embodying specifications for Impregnated Paper-Insulated Cable, under section 8, the first paragraph reads as follows, "The insulation resistance in a quantity having little significance except as a guide to the uniformity of the product; that is to say, a cable of high insulation resistance may be no better than one of comparatively low insulation resistance. Any important variation revealed by test should be investigated with a view to ascertaining whether the particular length has undesirable characteristics."

On the second page of Mr. Lee's paper appears the following statement "Although measurements of insulation resistance have been made on cables for years, and are still being made, the results as determined by the standardized procedure are of doubtful value as being indicative of the suitability or unsuitability of

cable for use." Mr. Lee further points out that in one case on thirteen lengths of 33-kv. cable manufactured during a three-months' period, the ratio of insulation resistance between the highest and lowest cable was as five to one. He goes one step further by saying that in another case, on eight reels of 22-kv. cable made from the same paper, treated in the same compound, in the same tank at the same time, the ratio of insulation resistance between the highest and lowest cables was as four to one, and yet there had never been any evidence to prove that one reel of cable was any better than the other. It is practically impossible in the light of our present knowledge to attempt to explain the cause for the variation in the last mentioned case because apparently the conditions were identical throughout.

In spite of all of the foregoing, inspectors have rejected cables for a lesser variation in insulation resistance, simply because the cable manufacturer has been unable to expound some theory that

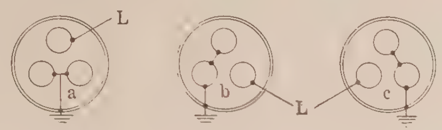


Fig. 9—Present Method of Measuring Insulation Resistance

would plausibly explain away these variations. On page 306 of the *Electrical World* issue of February 7th, 1925, under an article entitled "Progress in High-Voltage Cable Manufacture," various causes are cited that led one large cable purchaser to reject cables in 1924 and among these is listed insulation resistance. I am citing this case to show that although insulation resistance has not been considered of importance in determining high-quality cable, nevertheless, purchasers have used the results of this test to reject cables.

If insulation resistance as now measured is meaningless, is there some method for making this test that will prove of greater value? I believe there is.

Fig. 9 shown here represents the present method of making insulation-resistance measurements, namely, taking each conductor against the other two and the sheath which in turn is connected to earth. The faultiness of this method lies in the fact that we do not get the resistance of the various leakage paths separately, but collectively.

Fig. 10d shows conductor No. 1 against No. 2, No. 3 and sheath and ground as in the ordinary method. Fig. 10e shows conductor No. 2 against No. 3 using both poles of the source of d-c. potential and giving an absolute resistance of the field between conductors. Fig. 10f shows conductor No. 3 against the sheath and ground which enables us to explore the field between one conductor and the sheath. Fig. 10g shows conductors 1, 2 and 3 against the sheath which in turn enables us to explore the entire belt insulation.

This method uses only one additional test per reel of cable. It is not new, having been used as far back as 1910 to the speaker's recollection, but it certainly tends to reveal considerably more concerning the leakage paths in a cable than the one shown in Fig. 9 which is in general use at the present time. Furthermore, tests d, e, f and g have a further value in that they should bear a definite relationship to one another. For example if the value of insulation resistance obtained on

d....................	=	100 per cent
Test e should be approximately	=	160 per cent
Test f " " "	=	125 per cent
Test g " " "	=	70 per cent

With the different types of compounds in vogue today, where the compound used might be a mixture of some solid substance combined with a very fluid oil, the relationship between these tests might vary, but the same rate of variation should exist for that particular manufacturer's cables. There is one other point I would like to advance, that in the case where the insulation resistance appears to be low, the best way to determine whether it really is low, is to submit it to a three-minute electrification test. It is obvious that a conductor having a weak spot in its insulation cannot have the same rate of electrification for three minutes as a good conductor.

Power Factor, Dielectric Loss and Ionization

One of the largest cable purchasers in this country, recently reviewed the results of tests made during 1924 on a very large order of 13-kv. cable. This order was divided among six different cable manufacturers, the entire order having been inspected by what is undoubtedly the best testing organization in the country. This purchaser attempted to rate the six cable manufacturers according to the tests obtained, with the following results:

The manufacturer who had the greatest number of wrinkles in his insulation, the greatest number of creases in his paper, in short the poorest mechanical conditions in his cable, this same manufacturer who had the poorest impregnated cable, the lowest dielectric breakdown on a hot sample, the lowest dielectric breakdown on a cold sample after bending, this same manufacturer nevertheless, had the best ionization characteristics, namely, the smallest variation in power factor between stresses of 20 and 100 volts per mil, and also had the very lowest dielectric loss of all the other cables manufactured for this purchaser.

Let me bring up one more point. The company with which the speaker is associated in 1900 manufactured and installed the first 25,000-volt cable ever made in this country. Tests made recently on samples of this cable, showed that it had power factor of about 30 to 40 per cent at 100 deg. cent., that it would fail miserably on the bending test at − 10 deg. cent., and nevertheless this cable is operating to this very day with a smaller number of proportionate failures than any cable of similar design manufactured within the past ten years. One must necessarily ask the question as to how important are ionization, dielectric loss and power factor in the pre-determination of the suitability of a particular cable for a certain definite service.

In Fig. 24 of Mr. Lee's paper, sample No. 3 which had the highest initial power factor of all four samples nevertheless stood

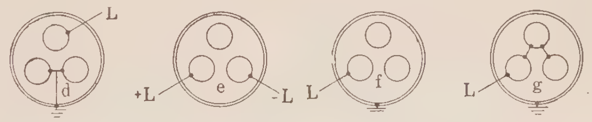


Fig. 10—Proposed Method of Measuring Insulation Resistance

up after 600 hours under the particular life test with a much smaller variation in power factor than the three others which had the lower initial values. All of the above in my estimation points clearly to the fact that power factor, dielectric loss and ionization have very little effect on the dielectric strength of a cable. In other words, a high power factor may or may not be accompanied by a high dielectric strength or vice versa. It seems to me that in the past, we have been a bit too rash in condemning certain types of cables, and overrating others on the basis of test performance on dielectric loss, power factor and ionization. In the paragraph immediately above Fig. 24 Mr. Lee states "The Effectiveness of the power factor-voltage test to separate poor cable from good, will have to be determined largely from experience." I am in absolute sympathy with Mr. Lee on that score and believe that although these measurements should not be discouraged, they should not be wholly used as a means for picking good cables from bad.

There is no question that of two cables, the one having the lower dielectric loss, will have the higher current-carrying

capacity. Let us confine ourselves therefore, to a reasonable value of power factors say a maximum of 5 per cent at 80 deg. cent. and 10 per cent at 100 deg. cent. and not attempt to try to make cables as perfect condensers. I can see no valid objection to any series of tests, but I do object to setting up these tests as a criterion, when their value as such has not been substantiated to the satisfaction of all concerned.

Samples

A 10-ft. sample cut from the end of a reel of cable can be used to reveal the following:

(a) It may show that the cable which it represents can stand a bending test, but it cannot reveal whether or not a 10-ft. sample cut from the other end of the cable, will be as good as the first in meeting the bending test.

(b) It may show that the cable which it represents has a high dielectric breakdown strength at 85 deg. cent. but there is nothing to indicate that a 10-ft. sample cut from the middle of the cable would yield as high a value. Tests made by the speaker on a number of samples cut from cables of different makes, have shown considerable variation in dielectric strength although the particular samples were taken adjacent to each other.

(c) A 10-ft. sample can however be made to show the physical make-up of the cable, the method of application of the insulation, the tensile strength of the insulation after drying and impregnation as compared to average values obtained on the new treated paper. In this way the inspector can tell whether the extremely high insulation resistance or low power factor obtained on a certain cable has been obtained at the expense of over-drying the paper insulation or whether it is inherent in the materials of which the cable has been manufactured.

I would however recommend, in the absence of any better suggestions, that these physical and electrical tests on samples be continued, always bearing in mind however, what the results obtained actually mean, and how far they can be applied in fixing cable quality.

Ratio of D-C. to A-C. in D-C. High-Voltage Testing of Cables

The subject of d-c. high-voltage testing has assured some importance of late and has also brought out some adverse criticism due to the arbitrary way in which a ratio of 2.4 has been fixed. We know that when testing a cable with alternating current the insulation is subjected to the maximum value of the voltage wave, we should therefore conclude that it would be able to stand an equivalent d-c. value which should be equal to 1.41 times the maximum a-c. value. Instead of this however, we find that an arbitrary value of 2.4 times the root-mean-square a-c. voltage has been taken, which gives a value of 1.7 times the maximum a-c. value, or an increase of over 21 per cent over the theoretical d-c. value to be used. With all due respect to the splendid work done by investigators both here and abroad, we are nevertheless confronted with the fact that the true ratio does depend upon the nature and structure of the material, upon the thickness of the insulation, upon the temperature of the material, the size and shape of the conductors and the rate of application of the applied potential. In other words of two similarly designed cables, one may be impregnated with a compound where the ratio of d-c. to a-c. may be more than 2.4 but the other may be less than that value, nevertheless both cables will have equal life when passing the a-c. installed voltage. In fairness to all concerned until more knowledge has been obtained on the results of this form of testing, I would suggest that each manufacturer be permitted to specify the ratio of d-c. to a-c. with which he would allow his cables to be tested. I am a firm believer in d-c. high-voltage testing of cables and expect to see the day when this form of testing will supercede all others now in use on both the factory and installation tests of cables.

Proof Testing After Installation

I am a firm believer in proof testing of cables and would recommend that twice a year, cables be tested at one and a half times the rated voltage for fifteen minutes. This would not overstress the cable insulation, and yet would be sufficient to give assurance that the cable was going to operate satisfactorily. Above all, I would earnestly recommend that the utility engineers inform the cable manufacturer of the results obtained on his cable during service, so that he can link up the experience gained in the factory with that obtained under actual operating conditions.

I. M. Stein: I was very much interested in the new galvanometer mentioned in this paper, and am sorry Mr. Lee didn't say more about it. Very often in a-c. measurements, progress is retarded by lack of a suitable detector. When we have a new one, it may open up paths for further progress. I hope, therefore, Mr. Lee can tell us more about his new detector.

I had the pleasure of reading Mr. Atkinson's paper on Bridge Measurements of Dielectric Losses, which appeared in the February issue of the *Electric Journal*. The detector used by Mr. Atkinson is somewhat different from Mr. Lee's and doesn't require any amplification. I am wondering if Mr. Lee can tell us the advantage of his detector over the one used by Mr. Atkinson, which I believe is an iron-core dynamometer.

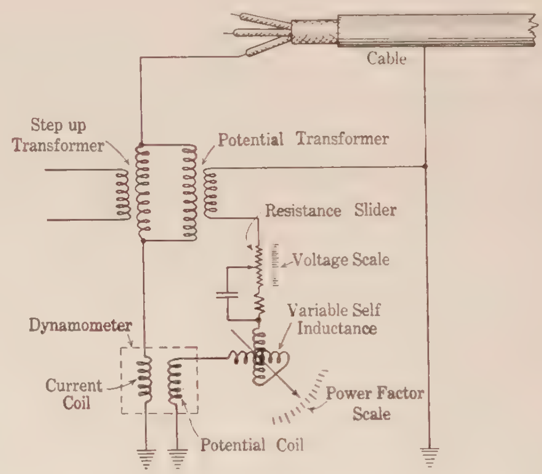


Fig. 11—Method of Measuring Power Factor of Cable

Bridge methods are known to have the advantage that the detector does not have to be calibrated, as in a bridge the detector is used as a null instrument. However, there are null methods which are not bridge methods, and one which is particularly suitable for measuring the power factor of cables is shown herewith in Fig. 11.

In the method shown an uncalibrated dynamometer serves as a null detector. This does not mean that there is no current flowing through one of the dynamometer coils, but rather that whatever current is flowing through one coil is in quadrature with that in the other.

The operation consists merely of rotating the inductometer until the dynamometer indicates zero; then the power factor is read directly from the scale of the inductometer, which may have a range of 0 to 5 per cent power factor.

A direct-reading power-factor scale is obtained by compensating (with a condenser and shunting resistance) for the residual inductance of the inductometer, the inductance of the potential coil and the phase angle of the potential transformer. The phase angle of the potential transformer may vary somewhat with the applied voltage, and one terminal of the compensating condenser is made adjustable to take care of this phase-angle change. The adjustable terminal of the condenser is coupled

with a voltage scale, and by setting the index of this scale to the working voltage, the change in phase angle of the potential transformer is compensated automatically.

It is usual to make tests at a low voltage and at five times this voltage. A range-changing switch may be provided, which operates on both the series coil and the potential coil in such a way as to give the same sensitivity at low voltage and five times low voltage, still retaining the direct-reading power-factor scale.

Unlike Mr. Atkinson's bridge arrangement, this equipment is intended for one use only; namely, for measuring the power factor on full-reel lengths of cable. Because of the simplicity of the arrangement, together with the direct-reading power-factor scale, only a few seconds are required to make each measurement.

H. W. Eales: It is probably fair to say that the need of users still exceeds the capability of the makers taken in numbers. The data developed in the paper applies mainly to short lengths of land cables of moderate voltages, with maximum of 33-kv.

Departure from these values brings the user into untried fields' Testing equipment has been designed for short lengths and moderate voltages, the number of makers equipped to test cables of very high voltage and long lengths being very few. Those who use 66-kv. to 132-kv. cable have very little experience of others to go by.

Fortunately, progress is made by trial. Unusual interest is therefore attached to the 66-kv. and 132-kv. installations at Cleveland and Schenectady respectively, and to the announced purchase of 35-kv. 350,000-cir. mil three-conductor sector submarine cables which are to be installed in the Mississippi River at St. Louis, each of which will be made up in half-mile lengths without splice, or twice the length heretofore attempted for this class of cable.

R. W. Wieseman: When alternating current is used for test ing, the wave shape of the applied voltage must remain the same throughout the test if consistent and dependable results are to be obtained. The sine wave is universally recognized as the standard wave form of voltage.

In cable testing it is extremely important that the generator should have a sine wave of voltage at all conditions of load. The generator voltage wave must therefore be free from all harmonics, especially tooth ripples. Otherwise the condenser capacity of the cable will greatly amplify the harmonics and the current wave will be saw-tooth instead of smooth, also additional dielectric losses will occur in the cable insulation. Furthermore, the generator must be stable throughout a wide voltage range when delivering large leading-zero-power-factor currents.

The testing generator shown by Fig. 4 of the paper was designed especially for cable testing. The excellent voltage-wave characteristics shown by Fig. 5, and by the table at the bottom of the third page, were obtained by a suitable choice of armature winding pitch and distribution. This type of generator can be short-circuited either three-phase or single-phase and the full normal-load current wave at zero voltage has a maximum deviation factor of only 1.5 per cent. A generator which has these characteristics is ideal for testing purposes.

P. W. Sothman: "Too many of our high-tension cables are coming up to specification but not up to expectation." In other words we test the proposed cable and find everything o. k. We put it into service and too large a percentage fails under operation, which shows that there is something wrong.

Quite often the consulting engineer is called into conference too late, *i. e.*, after trouble occurred which in many instances could have been avoided.

The characteristics which we know and have observed in overhead high-tension transmission lines are familiar to us. In underground cables the phenomena are often 10 to 20 times more severe in destructive effect than in overhead systems, due to the characteristics of a cable. The result of our work on overhead lines has been the design of surge-preventing or surge-reducing apparatus. In the underground systems nothing or very little has been done to make the over-potentials, surges, etc., harmless or to prevent them.

There is much room for closer cooperation between the cable manufacturer and the utility company. Each one should place the observed facts open to constructive criticism and discussion.

We learned from one discussor that the oil companies do not pay any too great attention to the quality of the raw materials delivered. The same is true of the paper manufacturers, which simply means that the cable manufacturers must treat the materials individually and cannot adopt a standard method. The treatment should be continued until tests prove the material has been made staisfactory.

The company which installs the cable also should do its part. I have seen cable pulled into duct in such a manner that the force applied was greater than the elastic limit of the cable. I even know of cases where new cables were pulled in two. Furthermore, the tools used in the laying of cables are often obsolete and not suitable. For instance, the pulleys through which the cables move often have flat grooves instead of grooves to fit the contours of the cable. The bearings in the guide pulleys are often common holes, whereas roller bearings would reduce the friction greatly and should be used. See Fig. 12. The consequence of such flat grooves is that the cable is damaged and will not perform properly.

Personally, I do not approve of our cable specifications in respect to dictating the minimum insulating thickness, as this does not spur the cable manufacturers to use the very best insulating material. My suggestion would be to say, "The insulation or distance between conductors should not be more than so many thousandths of an inch."

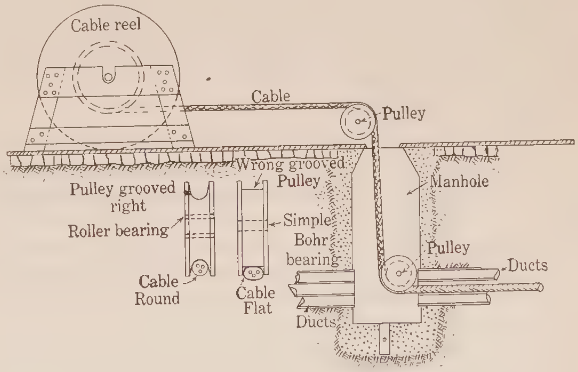


Fig. 12—Use of Pulleys for Pulling Cable

G. E. Luke (by letter): It is noted that the insulation resistance of the cable is measured after a one-minute application of the d-c. voltage. It is well known that such a reading is not the true ohmic resistance, since the transient current measured at this time interval may be several times greater than the final steady value due to the absorption effect. Hence, in a general way, this current will be a function of the power factor as shown in Figs. 1 and 2. It is suggested that this apparent resistance be measured at the end of a five or ten minute period since such a value would be very near to the true resistance; also a reading should be taken 10 to 30 seconds after voltage application. The ratio of the short-time reading to the long-time reading would be approximately the ratio of the absorption current to the true conduction current and would be an indication of the condition of the cable. (See paper by Phelps and Tanzer, A. I. E. E., 1923, p. 54.)

In the conclusions (1) the author says "Values of insulation resistance as heretofore obtained are of doubtful worth as a means for distinguishing between satisfactory and unsatisfactory cable." It is agreed that such measurements will not classify average-grade and high-grade cable but should in some

cases be able to distinguish between defective cables and passable cable. Thus in electric machines insulation resistance is taken before the high-voltage test in order to determine if the insulation is in condition to withstand the test. In such cases a very low resistance might indicate absorbed moisture or defective insulation.

In reading the data given in Figs. 10 to 13 on breakdown voltage-time curves at various temperatures, nothing could be found as to whether the temperature specified applied to the conductor, sheath or ambient air. For example, in Fig. 10 the temperature given was 25 deg. A voltage application of several times normal value will result in an elevation of the insulation temperature, hence it would be interesting to know the maximum insulation temperature for each test. This raises the question—Was the insulation breakdown due to high temperatures, chemical action, or to a dielectric puncture at normal temperatures? Of course combined effects may be present; however, it is suspected that the thermal action dominates.

It is suggested that the longer life of the cable on indurance run at 50 deg. cent. compared to 25 deg. cent. may be due to the lower viscosity of the impregnating compound and hence better distribution. If this is true, then it is an argument for the more fluid compounds.

Regarding the nature of the failures as outlined in two classes, (1) those where the puncture is radial and clean, and (2) those where the puncture is accompanied by deterioration, we also experience similar failures in armature coils. Those of the first class are usually due to a sudden application of a high voltage, while those of the second type are due to along-time application where cumulative chemical and thermal action may dominate. Failures of the first type may be due to voltage impulses of very short duration and may be classed as fundamental dielectric punctures.

The efforts to determine the "germ" of a breakdown by exploring the sheath temperatures were interesting. It would be of value to know the maximum internal insulation temperature corresponding to the sheath temperatures measured. This "hot-spot" correction would be considerably greater were it not for the equilization of the temperatures due to the conduction of heat along the heavy lead sheath.

The tree designs on some of the paper due to corona in the air spaces emphasize the fact that good impregnation is desirable. This raises the question—What per cent of the free space is filled in practise? In other words, what per cent of air space can be expected in such cables

E. S. Lee: It has been a great pleasure to have such excellent data presented to us in the discussion of this paper, particularly since the general conclusions of the paper are substantiated thereby.

Dr. Whitehead asks whether the curves between the power factor and insulation resistance give the order in which the observations were taken. The answer is, no. These data are plotted with the values of insulation resistance in ascending order, the lowest value first. Power factor values are plotted corresponding with the respective values of insulation resistance. This method of plotting (in order of ascending or descending values without regard to time) has considerable merit in cases where a large number of observations of a single quantity are obtained, since a graphic picture of the variation of the observations is clearly presented.

Regarding insulation resistance, I recognize, as all do, that we would like to have every piece of similar cable that comes from the tanks to be of the same insulation resistance, and that we would like to have that value just exactly the right value. At the expense of having it thought perhaps that our processes were not absolutely controlled, I have taken data to show the wide variation that may exist, and data have been presented by others showing this same wide variation in other cables. But what I had hoped to hear in discussion was that where the variation is large the cable will not live, and that where the variation is small the cable will live. There does not seem to be evidence to substantiate such a conclusion, however, which is all that I have tried to say in my paper.

As regards dielectric strenght, I think there is nothing else to say. I have merely suggested that present standardized values should be increased. In the absence of a rational basis for establishing values of proof-test voltage, we will have to arrive at such values through conference, and modify them from experience. Referring to Figs. 10 to 13, the temperatures indicated are ambient. Mr. Davidson's suggestion that the data are not extensive enough to justify lines being drawn through the points with precision is quite right. The lines might better have been drawn dotted. The purpose of the curves was to give a picture of the relation of the present standardized test voltages, rated voltages, and breakdown voltages.

Mr. Atkinson's scheme for adapting his bridge for measurement of power factor and dielectric power loss from three-phase supply is quite unique and appears to have great merit. It is quite possible that the Schering bridge may be somewhat similarly modified to allow of such measurement therewith.

Regarding Mr. Stein's question about the dynamometer, it is a remarkably fine instrument. It requires no tuning. We use it down in the factory. It stands on the table, with men working all around it, the crane running about ten or fifteen feet above it, and still it does its job. It is oil-filled. Its sensitivity is about two-fifths, I calculate, of what Mr. Atkinson gives in his paper, which is, I think, about 50 microamperes per millimeter. This would then be about 20 microamperes per millimeter. This is with the amplification, which is 100 or 125. So it isn't quite as sensitive as Mr. Atkinson's, but it does the work.

Mr. L. T. Robinson has often said: "When we used to have only one bridge in the laboratory, we could measure the resistance of anything very accurately and get its value. But when we got two bridges" he said, "we couldn't do quite as good a job in, measuring the resistance."

Well, we have had the dynamometer wattmeter method and used it. Mr. Shanklin operated with it and got good results. So when we applied to the Shering bridge we said, "Let's see what we shall get" and the paper shows you what we have been able to get under probably the best conditions. I show differences there in power factor of 0.002, that is, 0.2 per cent power factor, and in one case the bridge is high and in the other case the dynamometer is high, which is good. We have had results that vary as much as 0.4 per cent between the two measurements, but nothing more than that. So I feel that we are in very good agreement, and this little galvanometer does it.

As regards testing installed cable, I am gratified to have Mr. Davidson bring data which show that he has arranged that all of the d-c. tests which will be made on his system will be available in graphic form, with the voltage and the current values shown together on one instrument chart. Thus a permanent record of what has occurred will be available for study, which should enable us to learn more of the value of the d-c. test.

As regards the d-c. to a-c. breakdown voltage ratio, I wish again to call attention to the fact that while for any given breakdown voltage with a-c. there is no doubt a corresponding breakdown voltage with d-c., the relation between these two is dependent upon so many variables that each case has to be considered separately. Such a situation, therefore, requires caution in drawing conclusions relative thereto.

One more thing: We obtain the breakdown with d-c. and we obtain it with a-c., and we take the ratio. What we want, however, is a suitability test. That is, we want to put some kind of a test on the cable and not break the cable down. We want the cable to continue to live and be useful, but we want to know whether it is of such value that we ought to continue to let it live and be useful. That is the whole point.

The best we can do, is to obtain a proof-test voltage value

from what data we have, and we have the breakdown ratio. If the breakdown ratio for a particular kind of insulation is 2.4 and we say that is the best we have, then we are using the best we have, though that may not be exactly what we want. We have to find out by experience. But if we will recognize how we arrive at the value of d-c. to a-c. ratio, that is, from breakdown values, and that we are applying it to a proof test, then I am sure any differences that may appear on the surface will easily be straightened out, and everybody will be in absolute agreement.

As to Mr. Roper's tabulation, such an idea has merit and it seems that if we can continue to cooperate in obtaining what is considered by all to be a fair rating of the various items presented in that tabulation, it will be a step in the right direction. I want to note in this connection, however, that we are rating a good many properties that are not directly measurable. That is, we look at a thing, and we feel of it, or something of that kind, and then give it a rating. We would like, however, to be able to measure it in some way or another, which is what we must strive to do, as has been brought out by several.

In a lighter vein, if Mr. Duncan's remarks are recalled, it might be thought perhaps that the title of this paper should have been "Testing High Tension Iron-Impregnated-Paper-Insulated Lead-Covered Cable." But with all due respect to the paper samples that he may have, and with all due respect to what has been said the variations in oil, I want to say that the folks who supply the compound and the folks who supply the paper are interested in supplying the cable manufacturers with material that is as uniform as possible. And, in turn, the cable manufacturers are taking those materials, with what variations may exist therein, and are putting them through the necessary processes to produce long lengths of uniform insulation. A satisfactory means of determining the uniformity along a 500-ft. length of cable is not available however, since all the test methods now used (which do not destroy the cable) give a summation of the whole. One of the greatest needs of the art is a test method for determining the uniformity of insulation without harming it. Such is a subject for both industrial and collegiate research which ought to be actively pursued.

VOICE-FREQUENCY CARRIER TELEGRAPH SYSTEM FOR CABLES[1]

(Hamilton, Nyquist, Long and Phelps)

POLARIZED TELEGRAPH RELAYS[2]

(Fry and Gardner)

New York, N. Y., February 12, 1925

J. J. Pilloid: The three papers, *Metallic Polar-Duplex Telegraph System for Long Small-Gap Cables*, *Voice-Frequency Carrier Telegraph Systems for Cables* and *Polarized Telegraph Relays*, describe two telegraph systems particularly adapted for use on long toll cables, and a relay which is an important feature of the two systems. By long toll cables we mean here cables several hundred, or a thousand or more, miles long, used for telephone or telegraph purposes.

Such cables, as it has been reported to the Institute before, can each take the place of about ten heavily loaded open-wire lines, and they are used in sections where traffic is heavy. That means, of course, that there will be sections of the country where cables will not be placed for a good many years and so the older and existing telegraph systems (that is, the ground-return system) will be used for many years. One of the prime requisites, therefore, of these new systems, as brought out in these papers, is that they shall be adaptable for working with the existing systems.

There is just a mention of this idea on the fourth page of the voice-frequency carrier telegraph system paper, and if I do nothing else, I would like to emphasize that one statement. It is tucked away where you can hardly see it. It reads: "In the development of the voice-frequency carrier telegraph system, the central thought was the desirability of designing a system which would fit into the existing cable telephone and telegraph plant." As I pointed out before, it is also advisable that it fit into the existing open-wire telephone and telegraph plant.

The extent to which these systems will be used depends, of course, upon the development of this long toll cable plant and possibly a word as to the present development of that might be of interest. The cables at the present time are in service, as you know, from Boston to Washington and from New York through to Cleveland and to a point about half-way between Cleveland and Toledo. We expect to finish the cable into Toledo in a few weeks, where it will connect with a cable which is now in service between Toledo and Detroit. Cable is also in service for a distance of about 100 mi. east of Chicago, as far as South Bend, and work is under way on the remaining gap between Toledo and South Bend. It is expected that that section will be completed about October of this year. Also plans have been approved for a cable from St. Louis to Peoria and it is expected that this section will be completed to Chicago in 1926, so that we already have several long toll cables to operate these systems on, and are going to have more.

As the cables reach successive cities along the way toward their ultimate destinations the new telegraph systems and also the telephone systems join the older systems, and it is advantageous that both are easily adaptable and flexible enough for this purpose.

The voice-frequency telegraph system paper refers to the speed and message-carrying capacity of these systems. On the last page something is said about 6750 messages simultaneously each way on one full-sized cable. If such a cable, fully equipped with these systems, were devoted entirely to telegraph service, one could transmit all of the text of the five papers presented in this communication session and all of the discussions, in a fraction of a minute.

R. N. Nicely: The voice-frequency carrier telegraph system, providing as it does, a large number of telegraph circuits with a comparatively small amount of intermediate repeater apparatus, is well suited to use on long trunk routes between widely separated large cities from which distribution to outlying points is made by other telegraph systems. It will satisfactorily transmit signals at considerably higher speeds than is the case with aerial wire grounded polar duplex circuits used in the telephone plant and is therefore well suited to use with start-stop or multiplex printing telegraph apparatus.

It may be of interest to point out that the metallic polar duplex telegraph system and the voice-frequency carrier telegraph system may, if desired, be operated simultaneously on the same cable conductors.

METALLIC POLAR-DUPLEX TELEGRAPH SYSTEM FOR LONG SMALL-GAGE CABLES[1]

(Bell, Shanck and Branson)

New York, N. Y., February 12, 1925

R. N. Nicely: In connection with the extensive toll cable program of the Bell System, it has of course, been highly desirable that satisfactory methods be made available for utilizing the cable facilities for telegraph as well as for telephone service. This has been accomplished by the development of the metallic polar-duplex telegraph system and the voice-frequency carrier telegraph system. Each of these systems is adaptable to operation under widely varying cable circuit layout arrangements and each has certain characteristics which make it particularly suitable for use in connection with different specific requirements. In actual practise, each of the systems is a valuable supplement to the other.

The metallic polar-duplex system, in addition to being extensively used on long trunk-cable routes, is well adapted to tele-

1. A. I. E. E. Journal, Vol. XLIV, March, p. 213.
2. A. I. E. E. Journal, Vol. XLIV, March, p. 223.

1. A. I. E. E. Journal, Vol. XLIV, April, p. 378.

graph-circuit distribution from large centers to outlying towns or cities reached by cable as well as to telegraph stations at the center itself or at outlying points reached by aerial wire circuits.

The metallic system is of value also during the construction of long toll cables which, as in the case of the New York-Chicago cable, may be extended over a period of several years. As the cable is extended it is of course, desirable that heavily loaded aerial wire lines on or near the cable route be lightened by transferring at least a part of the circuits to completed sections of the cable. The metallic telegraph repeater being adapted for operation on metallic cable circuits in one direction and on aerial wire or grounded cable circuits in the other, is particularly well suited for use at points where the two types of circuits are joined. Furthermore, the metallic repeater being a practically self-contained unit, may be readily moved from point to point if desired, as the cable construction advances.

With the metallic telegraph system, intermediate repeaters are in general, required at more frequent intervals than is the case on aerial wire telegraph circuits but, owing to the greater stability of the cable circuits, this apparent disadvantage is offset by the very small amount of equipment adjustment required by the metallic apparatus during operation.

J. H. Bell: To an old-time telegraph man used to the noises in a large telegraph office, a visit to one of the small-gage cable telegraph repeater stations where practically all the repeaters are of the type described in this paper would be somewhat of a surprise. The quietness of the room is broken only by the click of a sounder during periodic tests by the repeater attendants listening for a moment or two to passing signals. I believe at first it was thought the repeater attendants who had been accustomed for so long to the clatter of sounders would take unkindly to working in a nice quiet office, but in that regard the psychology was wrong. I am safe in saying, I think, that the repeater men much prefer the new conditions.

There is one apparatus unit in the sets to which I would like to refer, namely, the dial-type switch for enabling the value of capacity in the artificial line to be varied. To one accustomed to juggle with five plugs or levers to secure some one of the thirty-one possible values of capacity, the convenience of stepping round a dial, adding, say, 0.1 micro-farad at each step and getting values of between 0.1 and 3.9 microfarads, is immediately noticeable and appreciated. One can strike a duplex balance in a fraction of the time taken with the older apparatus.

In regard to the operation of the system, it should perhaps be pointed out that the speeds of operation given in the paper do not necessarily represent the maximum speeds obtainable. In designing the system the aim was to provide for high-grade service at fast hand speed; that is, about 15 dots per second. The vibrating circuits are consequently permanently set for operation at about that speed so that at higher speeds the vibrating feature would probably be detrimental rather than beneficial.

The most important unit of a telegraph system is the relay. One might say it is the heart of the system, so that it is difficult to discuss a new system without making some reference to its heart. The sensitive polarized relay described in the paper by Messrs. Fry and Gardner[2] was designed primarily for the metallic system, although it has been found particularly applicable to the voice-frequency carrier system[3] and the high-frequency carrier system which was described in a paper presented at an Institute meeting some years ago. With the improvements which have recently been incorporated in it, namely, the accurately balanced windings, permalloy magnetic material, the new contact material, the anti-chatter armature, I think we have in it now a high-grade polar relay which is likely to be our standard for several years to come.

In the discussion of a telegraph paper before the British Institute of Electrical Engineers recently, one of the speakers very cleverly compared the art of communication with the art of transportation. He said the telephone was like the passenger service, a very personal affair demanding quick service, whereas the telegraph was like the express service, where one hands over a message to be transmitted or transported and the operating company does the rest. Of course, this simile does not apply very aptly to the telegraph service of the Bell System. The Bell telegraph service furnishes to each customer or patron a single-track or double-track private express railroad for his exclusive use, and by the ingenious compositing scheme the same lines are made use of for a public passenger service, without any fear of collisions.

Perhaps I may be permitted to borrow the simile and to enlarge upon it by saying that in the metallic cable system and the voice-frequency system we have provided for these private express railroad services a much improved rolling stock.

Note: See also discussion on Voice-Frequency Carrier Telegraph Systems for Cables, by B. P. Hamilton, H. Nyquist, M. B. Long and W. A. Phelps, and Polarized Telegraph Relays, by J. R. Fry and L. A. Gardner. (Preceding page.)

2. *Polarized Telegraph Relays*, J. R. Fry and L. A. Gardner, A. I. E. E. Journal, March 1925, page 223.

3. *Voice-Frequency Carrier Telegraph System for Long Small-Gage Cables*, Hamilton, Nyquist, Long and Phelps, A. I. E. E. Journal, March 1925, page 213.

COMPLETE SYNCHRONOUS MOTOR EXCITATION CHARACTERISTICS[1]

(Douglas, Engeset and Jones)

New York, N. Y., February 10, 1925

Q. Graham: (communicated): To those who are familiar with synchronous motor *V* curves in the normal working region only, the shape of the curves in their remote upper portions may seem to be of little importance. Yet they do form a fascinating study and they have a certain practical importance.

A synchronous machine having negligible resistance in the armature winding and negligible saturation could be made to furnish armature current in proportion to its field current through an unlimited range. As soon as armature resistance is introduced this relation is changed and an upper limit for armature current is reached. The curves then take the shape which the authors show in their Fig. 4.

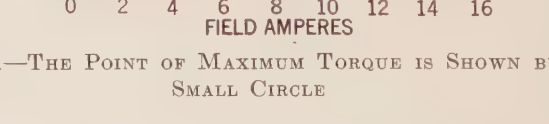


Fig. 1—The Point of Maximum Torque is Shown by the Small Circle

In order to point out some of the interesting relations that exist I have calculated the curve of zero torque for the authors' machine, having had access to the manufacturer's records. This calculated curve along with the corresponding curves of induced voltage and angular position of the rotor are shown in Fig. 1. The corresponding branches of the three curves are shown by the arrows. The calculated curve agrees fairly well with the test curve shown in the paper.

If we proceed from the point of zero armature current an increase in field current gives an increase in armature current until

1. A. I. E. E. Journal, Vol. XLIV, January, p. 11.

the point of maximum field current is reached. Here the displacement of the rotor is nearly 90 deg. A slight reduction of field current and an increase in displacement brings the armature current to a maximum as the displacement reaches 90 deg. At this point the power factor of the machine is unity and the resistance drop in the winding is just equal to the line voltage. A further reduction in excitation accompanied by a greater phase displacement of the rotor reduced the armature current again. The next point of interest occurs where the induced voltage is zero. That is, the impedance drop in the winding is equal to the line voltage and the field and armature ampere turns across the air gap are neutralized. From this point the curves proceed to the position of zero field current. To continue the increasing

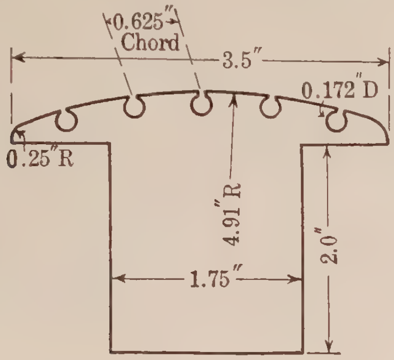


Fig. 2

displacement of the rotor after zero field current is reached the excitation must be reversed. An increase of field in the reversed direction will then bring the armature current back to zero and the complete path will have been traversed. It will be noted that the rotor displacement has reached 180 deg. but since the excitation has been reversed a condition of stability exists. In passing through the point of zero excitation it would have been satisfactory to consider the rotor as going through an instantaneous shift in position of 180 deg. and the excitation as remaining positive.

It is interesting to consider these curves from the standpoint of power input and output and thereby examine the region beyond the point of maximum excitation. Under any condition the power input is divided between the $I^2 R$ loss in the winding and the output which appears as torque at the shaft. For pure condenser operation, or zero torque, the input is entirely absorbed as loss in the winding. The following conclusions may be drawn at once:

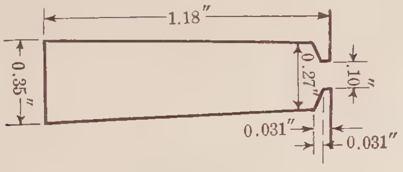


Fig. 3

1. For any torque curve, including the zero torque curve, the power factor is unity at the point of maximum armature current.

2. The maximum torque point occurs with an armature current which is half of the maximum current on the zero torque curve. The input is then equally divided between loss and output.

3. For armature and field currents beyond the range shown by the curves the loss exceeds the electrical input and torque must be supplied to the shaft. The machine then becomes a generator loaded on its own windings.

A study of the complete excitation characteristics of synchronous motors has proved worthwhile in connection with applications requiring extremely low frequency operation. If the authors are inclined to make further experiments they might operat etheir machine at 25 cycles or even lower and thus have the equivalent of a higher resistance armature with its concomitant effects.

The following design data on the authors' machine may be of interest.

Stator:

15 in. outside diameter, effective (punching is not circular.)
10 in. inside diameter.
5 in. axial length.
72 slots. See Fig. 3 for dimensions.
22 conductors per slot. Each conductor consisting of two 0.57 in. diam. wires in parallel.
Winding in three parallel groups, star-connected, for 220 volts.
Throw of coils from slot No. 1 to slot No. 10 or a pitch of 9 slots.
Single air gap 0.094 in.

Rotor;

Six poles. See Fig. 2 for dimensions.
Damper winding; 5 bars per pole, each 0.162 in. diam. copper.
End ring 0.156 in. × 0.75 in. copper.
Field winding: 185 turns per pole of 0.057 in. × 0.081 in. copper ribbon.

R. W. Wieseman: The unstable portion of the excitation curve or phase characteristic of a synchronous motor has never been obtained experimentally, so far as we know, and therefore the authors of this paper are to be commended for obtaining the complete synchronous motor excitation curve. However, these curves are apparently more valuable from the academic standpoint than from the practical standpoint because a synchronous motor can not be operated in practise at the unstable part of its excitation characteristic.

The authors state that in Fig. 4 no evidence of a saturated condition is observed in the excitation curves at large field currents. I wish to point out that practically no saturation could exist in a machine which is operated at one-eleventh voltage and consequently one-eleventh of its normal magnetic flux density. Saturation will only occur and affect the shape of the curves when the motor is operated near normal flux densities. No effects of saturation are noted in Fig. 3, which shows the excitation characteristics at one-half normal densities.

In the description of the method of finding the synchronous impedance shown by Fig. 6, it is stated that this method gives no clue as to how the impedance will vary with power factor, and that to obtain this variation an arrangement shown by Fig. 7 is necessary. The variation of impedance with power factor can be obtained very easily with the arrangement shown by Fig. 6 if resistance is connected in series or in parallel with the inductance.

This paper states that the synchronous impedance of a synchronous motor varies with the several conditions of load. It is easier and also more practical to consider the synchronous impedance made up of two components: armature leakage reactance and armature reaction. The armature resistance can be neglected. In a salient pole machine the armature reactance is maximum with unity power factor currents and minimum at zero power factor, whereas the effect of armature reaction is minimum at unity power-factor and maximum at zero power factor. Therefore, the manner in which the synchronous impedance varies depends upon the inherent design of the machine as well as the load conditions.

V. Karapetoff (communicated): The authors deserve much credit for having shown that the so-called unstable portions of load characteristics of a synchronous machine may be obtained experimentally, by coupling two machines mechanically at an

adjustable angle[2]. The instability is purely mechanical, and is due to the fact that in regular operation the machine (whether a generator or a motor) is allowed to change its torque angle with the load. When two synchronous machines are coupled mechanically and also connected electrically, this angle is entirely under the observer's control, and the stability is that of the set and not of the individual machines. While the practical application of the method is somewhat limited because two mechanically and adjustably coupled machines are but seldom available, the method should prove of interest in experimental studies of armature reaction and reactance, and in checking various proposed theories and performance diagrams of synchronous machines. Just now, the stability limit in the generator range is of considerable practical importance in super-power plants in which the generator characteristics limit the amount of power which can be transmitted over a given line. Possibly, the range near and beyond the generator stability limit can also be conveniently studied by means of two adjustably coupled machines. Then, if the observed performance, on small machines checks with that predicted by theory, the designer may compute the power limit of his super-power generators with much more confidence.

The value of the paper would be much enhanced if complete design data of the machines were available. It is to be hoped that the maker of the machines will be generous enough to contribute these data to this discussion, in order that the observed curves may be checked with theoretical diagrams. Perhaps with the theory of two reactions, when properly applied, the observed hump in Fig. 3 could be interpreted or predicted. In the range under consideration, the machine is unsaturated, and Blondel's theory should apply with considerable accuracy.

I am at a loss to understand the latter part of the paper, purporting to analyze the effect of the current, saturation, and power factor upon the magnitude of synchronous impedance. The concept of synchronous reactance was introduced in the early days of a-c. engineering, and served its useful purpose in those days, but it is almost unbelievable that any one should now attempt to interpret the observed performance characteristics of a synchronous machine with salient poles in terms of a variable synchronous reactance. The authors should have separated the direct armature reaction from the leakage reactance, using the zero-power-factor load curve,[3] and then estimated the transverse armature reaction from the performance at unity power factor and the observed torque angle. This would have given them a rational basis for an interpretation of the other observed curves and for a judgement about the accuracy of the method of two armature reactions. Having instead bunched together all these heterogeneous factors into a physically irrational concept of "synchronous impedance," they have reached conclusions apt to befog rather than to clear up the issue.

Equally incomprehensible to me are their references to my "Magnetic Circuit." They speak of the observed ratio (2 to 3) of the synchronous impedance at unity power factor to that at zero power factor and state that it is considerably higher than that computed by me. My formulas and computations refer to the direct and transverse components of the armature reaction, and not to synchronous impedance, which latter I have used in my writings only in order to show its limitations and inadequacy. My values could be checked with the experimental results only by computations involving the design constants of the machines, and there is nothing in the paper to indicate that the authors have used the design data in their conclusions. The authors also ascribe to me the statement (without giving the page) that the impedance at 100 per cent power factor should be independent of saturation. Since I do not use the concept of synchronous impedance in the "Magnetic Circuit" at all, it is not clear how and where I could have made such a statement. At unity power factor at the terminals, there is not an inconsiderable internal phase angle and a corresponding direct reaction. With higher saturation, the effect of this direct reaction upon the net flux is of course less. The transverse reaction and the leakage coefficient are also affected by the saturation of the pole tips, although these factors are difficult to take into account theoretically.

Within the last six or seven years, Prof. Blondel has published in various French periodicals a number of excellent articles, further explaining and extending the application of his theory of two armature reactions of the synchronous machine. In the light of these painstaking researches, the interpretation of the results by the authors is quite out of date. They could render real service to the profession if they would further experiment with the same machines, and use their results to build up, step by step, a consistent and accurate theory of synchronous machines, and also critically check various modifications of the present theories.

J. F. H. Douglas: We wish to concur in what Mr. Wieseman has said on saturation, and on the armature leakage reactance probably being larger at high power factors. We wish to thank

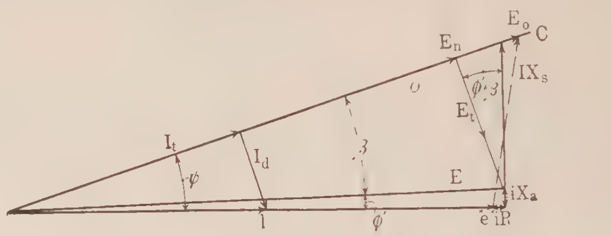


Fig. 4—Vector Diagram Comparing Blondel Method with Synchronous Impedance

Professor Karatpetoff for suggestions for future tests, and for bibliographic references. We find the comment and calculations of Mr. Graham of interest and his discussion of stability illuminating. The design data furnished will be valuable. We wish to call attention to fact that Mr. Graham's and Mr. Wieseman's statements as to whether armature resistance is negligible can be harmonized. The armature resistance is negligible at normal frequency and impressed voltage, if the motor is not greatly over excited it must be taken into account otherwise.

We wish to express a doubt whether a simple load test using resistance as well as reactance, will give the synchronous reactance. For illustration, in Fig. 1, if E_o is measured at no load, one might think the synchronous reactance drop to be perpendicular to the current and might get an erroneous value for the same. Fig. 9 in our paper, indicates that the $I\ X_s$ drop is not perpendicular to the current in all cases. Professor Karapetoff's remark is quite to the point here that considerably more experiment is needed.

We are criticised by Professor Karapetoff for the use of synchronous impedance on various grounds. We consider the term too firmly entranced in the texts, and by implication in the A. I. E. E. rule for regulation, to be ignored. We consider it useful as a concept for the very fact that it gathers up a number of components. (1) In qualitative explanations it affords a simple way of speaking of the effects of changing the excitation of a synchronous motor, or of putting a load upon it. (2) For approximate calculations it affords a quick method of computation. (3) When allowance is made for the fact that at high power factors the measured impedance is less, (and the reason why is easily explained), it affords a simple basis for calculating period of hunting and synchronizing torque, and a simple basis for discussing the

2. Testing of alternators by means of two identical machines rigidly coupled at an angle was suggested by A. Blondel in 1892 and more fully described by him before the International Electrical Congress in St. Louis, 1904; Trans. Vol. 1, p. 620.

3. V. Karapetoff, Experimental Electrical Engineering, Vol. I, Third edition, Chap. 20.

accuracy of the A. I. E. E. method for regulation at high power-factors.

Defined as the ratio of cause to effect, of antecedant to consequent, as voltage across a switch to current flowing after closing it, it is in accord in reasoning with many of Professor Karapetoff's own explanations. To term it a collection of heterogeneous factors is not quite just. The distortion of flux and the drop in voltage resulting from it has only one "genesis" or origin—the armature m. m. f. We may, if we wish, divide the cause into components parallell to and perpendicular to the poles. We may divide the effect into components, those fluxes, and e. m. fs. strictly proportional to armature current and those which, owing to saturation, are not so proportional,—reactances, and reactions. This is a question of accuracy and convenience for the purposes in hand.

Synchronous impedance is criticised as physically irrational. It is empirical, while the Blondel method is highly theoretical. However, all theories contain irrational elements in the sense of items which are approximations of the physical reality. In this sense, the Blondel theory is also irrational. To mention one point, in the "Magnetic Circuit" it is assumed that armature leakage reactance is an absolute constant. This is the basis of the criticism that we should have worked up our data in a certain way, but if we had done that we would have come under Mr. Wieseman's criticism," in salient pole machines, the armature reactance is a maximum with unity power factor, and a minimum with zero power factor," a statement, which we think may be correct. To mention another point, the co-efficient of cross reaction or relation between the voltage induced to the current, is assumed as a constant. This relation is derived in Karapetoff's Magnetic Circuit by the analogy of "fictitious poles," which show no saturation. This is an irrational element, that only brings home the point that all our theories are approximations. We have no objection to using the Blondel theory as a second approximation, until a better is found, but we think of synchronous impedance as a first approximation.

That the Blondel theory does need improvement, we feel most strongly. Our data will not agree with Professor Karapetoff's formulas. When we try to get synchronous impedance from his diagrams at 100 per cent power factor and at low saturations the result is less than that shown by our tests. The value taken off his diagrams is independent of saturation, contrary to our experiments. We did not mean to imply that he used or calculated synchronous impedance himself. However, to be specific, we take the synchronous impedance at unity power factor to be approximately equal to

$$X_{s(100)} = X_a + (E_t'/i) = X_a + (0.3\ K_b mnv)$$

the quantities appearing in part in his equation **84** page 156.

The Fig. 4 herewith is Fig. 40 of page 150 of the Magnetic Circuit, drawn for 100 per cent power factor with three vectors added. The solid line $O\ E_o$ is the no-load voltage along the polar axis $O\ C$, the dotted line $E\ t'$ from equation **84** is drawn in its proper phase position, perpendicular to the current, and terminating on the line $O\ E_o$. The dotted line joining e and E_o is what we call, and what is usually called the synchronous impedance drop. There is nothing in the Magnetic Circuit to indicate that E_t' even has a position, but by reference to the equation after Eq. (**186**), namely,

$$E_t' \text{ Sin } (\phi + \beta) = E \text{ Sin } (\beta)$$

we see that the line E_t' of our diagram does meet these conditions. In the above diagram $I\ Z_s$ is numerically very close to $I\ X_a + E_t'$.

Numerically we note that X_a may be taken from our Fig. 12 as also may the direct reaction, given by Eq. **79** in the Magnetic Circuit. We find from our Fig. 12 that the value of (Xa) is too small to measure. We attribute then the whole effect to reaction. We find that an armature current of 35 amperes in Fig. 12 neutralizes a field current of 7 amperes. Comparing equations **79** and **84** in the Magnetic Circuit we note the constant in one is 40 per cent of that in the other, with V the slope of the saturation curve included. We compute the slope to be 31 volts per ampere. We compute $X_{s100} = 0.4(7/35)\ 31 = 2.5$ ohms.

When we refer to our Fig. 10 we see that this value is much too small when machine is not saturated, and that the value of the reactance is not a constant, as indicated by the above interpretation of the Theory in the Magnetic Circuit, but actually a variable affected by saturation of the machine. Fig. 4 shows clearly that the direct reaction can not be a major item being nearly horizon-

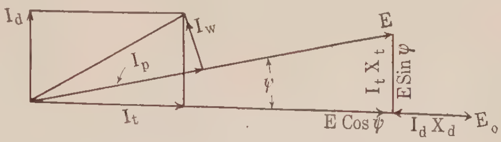


FIG. 5—SIMPLIFIED BLONDEL DIAGRAM

tal but that the saturation of pole tips affects the transverse reaction. As Professor Karapetoff admits, this factor is difficult to take into account theoretically but the variation of values in Fig. 10 of our paper at unity power factor from 3.2 to 1.6 ohms indicates that the reluctance of the transverse flux path is approximately doubled, by saturation. This change is so large that it is difficult to see how one can avoid the conclusion that the theory of transverse reaction needs considerable improvement.

With the data now available from the manufacturers it would be easy to follow the suggestion made to check the shape of the hump in our curves by the Blondel theory. The following cal-

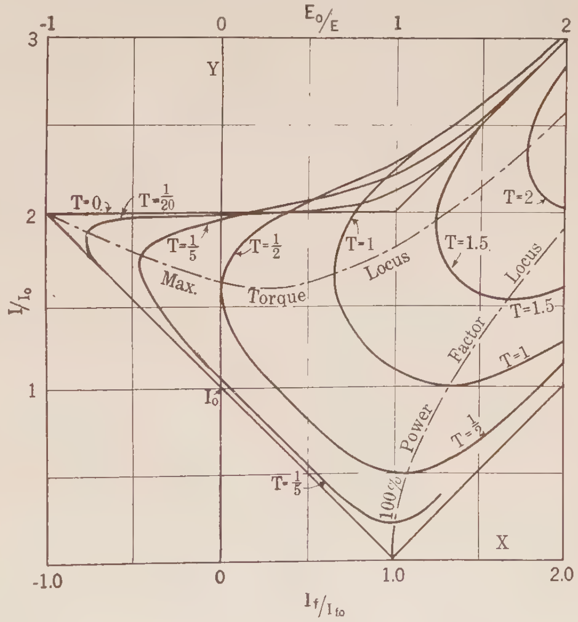


FIG. 6

culation was made before this data was supplied, but checks so well in a general way, that on this point Professor Karapetoff may consider himself well vindicated. Let us assume that resistance may be neglected, and that we have only to consider two reactances X_t for cross-magnetizing current, and X_d for direct reaction component of the current. This is a rather crude simplification of the Blondel theory that will hold fairly well with small saturation. Fig. 5 gives the vector diagram. The impressed voltage is E, the induced voltage at no load E_o, shows by its magnitude the field current, and by its phase the angle the pole has fallen behind. The current I may be resolved into components I_d and I_t in quadrature and in phase with the pole centers. By assumption I_d is caused by voltage component

$E_o - E \cos \psi$ and is governed by X_d, while I_t is due to $E \sin \psi$ and is governed by X_t. Thus

$$I_t = E \sin(\psi)/X_t; \qquad I_d = (E_o - E \cos(\psi))/X_d \qquad (1) \& (2)$$

The ordinates Y of a set of V curves may be taken as the ratio the armature current to any current such as $(E/X_d) = I_o$ as a basis. The abscissas may be taken as the ratio of field currents of induced no load volts E_o/E. If we call $X_d/X_t = K$, I_p the power, and I_{qw} the wattless components of the current, we have the following:

$$I_t = I_o K \sin(\psi); \qquad I_d = I_o(X - \cos(\psi) \qquad (3) \& (4)$$

$$T = I/I_o 2 \sin(\psi) \left((K-1) \cos(\psi) + X \right) \qquad (5)$$

$$I_w = I_o (X \cos(\phi) - K + (K-1) \cos^2 \psi) \qquad (6)$$

$$I = \gamma (I_p^2 + I_w^2) \qquad (7)$$

We assumed $K = 2$, $T = 0.05$, 0.02, 0.5, 1.0, 1.5, and 2.0; we assumed values of $\psi = 2°$, 5°, 10°, 20°, 30°, ...170°, and solved Eq. (5) for X. We then solved Eq. (6) for I_w and Eq. (7) for I. We have plotted the values of: I thus computed against X in Fig. 6. These curves in the main agree with our experiments, and certainly bear out the contention that the Blondel theory applies quite accurately at low flux densities.

COOPERATIVE INVESTIGATIONS OF RADIO WAVE PHENOMENA

The continuing expansion in the uses of radio, and the unexpected phenomena encountered in the very high frequencies now so extensively employed, make important the determination of the laws governing radio transmission. Fuller knowledge of these phenomena is necessary before radio can fully grapple with the limitations at present imposed upon it by atmospheric disturbances, interference, and fading. To this end a number of university and other laboratories are engaging in a measurement program under the direction of the Bureau of Standards. The work includes measurements of field intensity, fading, direction variation and atmospheric disturbances, at the broadcast and higher frequencies.

The first series of observations was made in connection with the solar eclipse of January 24. Cooperating in the program initiated by Mr. G. W. Pickard, quantitative measurements of the signal intensity variations and direction shifts of transmission from several stations were conducted by the Bureau of Standards and a number of other laboratories, most of them in the northeastern part of the United States and southern part of Canada. Records were made on the morning of the eclipse and, for comparison purposes, on two days before and two days after. These observations showed that the eclipse gave rise to effects intermediate between those characterizing day and night. Much interest was stimulated in the measurement work and an increasing number of laboratories are preparing apparatus for participation in the further work.

In a second series of observations started on March 24, the object of study was the marked changes of transmission occurring at sunset. All participants concentrated on the transmission of a single broadcasting station, WGY of the General Electric Company, Schenectady, N. Y. The results of these observations will be studied and a report issued later.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

COMPOSITE COMMERCIAL LIGHTING UNIT

A novel method of illustrating several types of interior lighting systems has been developed for commercial lighting demonstration rooms in which the principles of illumination are emphatically disclosed. The system affords a means whereby the demonstration room may be illuminated either by indirect, the heavy density semi-indirect, the light density semi-indirect, the enclosing or the direct type of lighting.

Fig. 1—Composite Unit

These variations are obtained by using the composite unit illustrated in Fig. 1. This unit, with its special reflector, uses fourteen incandescent lamps, including a 400-watt and a 100-watt projection lamp and two 200's, one 150 and one 100, three 75 and five 50-watt lamps. Due to the limited space available in the luminaire it was necessary to have four lamps made in special bulbs.

The lamps are arranged on seven circuits. The several variations in output from the unit are obtained by using different combinations of lamps. More complete control is obtained by including resistor units in some of the circuits, thus making it possible to operate those lamps at lower voltages. The output of the unit for each variation is equivalent to that of a commercial unit using a 500-watt lamp. This feature makes all effects comparable.

The unit has been found satisfactory for demonstration work at conventions, shows, etc., and is particularly applicable as laboratory equipment to supplement technical lectures on illumination design. It is not intended for usual lighting purposes.

JOURNAL
OF THE
American Institute
of Electrical
Engineers

PUBLISHED MONTHLY BY THE A. I. E. E.
33 West 39th Street, New York
Under the Direction of the Publication Committee

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Philippines; $10.50 to Canada and $11.00 to all other countries. Single copies $1.00. Volumes begin with the January issue.

Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

Picked Technical Papers and Recreation, Features of Annual Convention

The schedule of events has practically been completed for the Annual Convention of the Institute which will be held at the United States Hotel, Saratoga Springs, N. Y., June 22-26. The technical program, though limited in volume, will cover many branches of interest and the material will be specially selected for quality. As customary at the Annual Convention, the recreational features will be emphasized and all of the afternoons will be free for sports, automobile riding and other pleasures.

Short and illuminating reviews of the progress in various live lines of electrical achievement will be presented by the respective technical committees Tuesday and Wednesday of the convention week. A few carefully chosen papers on diverse topics will be offered on Thursday and Friday. A list of the papers is given below.

As a special technical feature two very able papers on hydroelectric development will be presented at an evening meeting, probably Thursday evening. *Power Possibilities at Muscle Shoals* is the first paper and it will be presented by Samuel S. Wyer, consulting engineer. William S. Lee, Vice-President and Chief Engineer, Southern Power Company, will present the other paper which describes the hydroelectric development of the Duke-Price Power Company, Ltd., on the Saguenay River, at Isle Maligne, Quebec.

At another evening meeting, probably Wednesday, a discussion of engineering education is planned and it is expected that William E. Wickenden, Director of Investigations of the Society for the promotion of Engineering Education, will give an address. Mr. Wickenden has for several months been in Europe studying the educational methods of many countries there.

A report on the extensive progress in Standards work which has been made during the last year will be presented on Tuesday or Wednesday morning.

The first day of the convention will be devoted to the meeting of the Section delegates, held under auspices of the Sections Committee. At this meeting the problems and plans of the Institute Sections will be discussed. Matters which relate to the welfare and improvement of Section activities will be acted upon.

Every afternoon, as already mentioned, will be free for recreation. Golf contests and tennis tournaments will be entered by both ladies and men. Located as it is at the foot of the Adirondacks, Saratoga is blest with many beautiful automobile drives. A number of the members plan to take their cars to the convention in order to avail themselves of the opportunities for delightful trips.

On Tuesday evening there will be a reception followed by a dance. There will also be dancing on other evenings.

One event of interest will be an afternoon trip to the works of the General Electric Company at Schenectady, which is located about twenty miles from the Springs.

The Annual Convention is the Institute gathering in which entertainment and recreation are most widely entered into. This meeting will be especially enjoyable to the ladies and a large number of them will be present. A very attractive program for their pleasure has been arranged.

The general committee appointed by the President to handle the convention consists of: J. R. Craighead, Chairman, H. H. Dewey, N. F. Hanley, L. W. W. Morrow, F. W. Peters, L. T. Robinson, Harold B. Smith, John B. Taylor and C. S. Van Dyke.

The chairmen of the subcommittees appointed to date are as follows: F. W. Peters, Finance, J. B. Taylor, Entertainment and Social Events, H. H. Dewey, Games and Athletics, C. S. Van Dyke, Excursions, L. T. Robinson, Music, C. E. Mochrie, Transportation, H. W. Samson, Publicity, and W. A. Sredenschek, Hotel Accommodations.

TENTATIVE LIST OF TECHNICAL PAPERS FOR 1925 ANNUAL CONVENTION

Engineering and Economic Elements of Two-Phase Five-Wire Distribution, by P. H. Chase, Philadelphia Electric Co.

The Oil Circuit Breaker Situation from an Operator's Viewpoint, by E. C. Stone, Duquesne Light Co.

The Quadrant Electrometer, by W. B. Kouwenhoven, Johns Hopkins University

A New Method and Means for Measuring Dielectric Losses, by R. E. Marbury, Westinghouse Electric & Mfg. Co.

Separate Leakage Reactance of Transformer Windings, by O. G. C. Dahl, Massachusetts Institute of Technology

Transformer Harmonics and Their Distribution, by O. G. C. Dahl, Massachusetts Institute of Technology

Two-Phase Six-Phase Transformers, by A. Boyajian, General Electric Co.

Resolution of Transformer Reactances into Primary and Secondary Reactances, by A. Boyajian, General Electric Co.

Losses in Iron Under the Action of Superposed A-C. and D-C. Excitations, by O. E. Charlton, Alabama Power Co., and J. E. Jackson, General Electric Co.

Study of Time Lag of the Needle Gap, by K. B. McEachron and E. J. Wade, both of General Electric Co.

Oscillograph Solution of Electro-Mechanical Systems, by C. A. Nickle, General Electric Co.

The Klydonograph and Its Application to Surge Investigations, by J. H. Cox and J. W. Legg, both of Westinghouse Electric & Mfg. Co.

Overvoltages on Transmission Systems Due to Dropping of Load, by E. J. Burnham, General Electric Co.

The Loaded Submarine Telegraph Cable, by O. E. Buckley, Bell Telephone Laboratories, Inc.

The 540,000-H. P. Hydroelectric Development at Isle Maligne, Quebec, by W. S. Lee, Southern Power Co.

Power Possibilities at Muscle Shoals, by S. S. Wyer, Consulting Engineer.

The Regional Meeting at Swampscott

All arrangements have been completed for the Regional Meeting of the Northeastern District which will be held at the New Ocean House, Swampscott, Mass., May 7, 8 and 9. The recreational and social events have been worked out in detail and an excellent technical program is ready for presentation. The features of the meeting were covered in the April issue of the JOURNAL, page 427. The program of the technical sessions is given below.

AEROPLANE VIEW NEW OCEAN HOUSE AND PURITAN HALL

TECHNICAL PROGRAM OF SWAMPSCOTT MEETING

MAY 7, 10:00 A. M.

TRANSMISSION SESSION

Overvoltages on Transmission Systems Due to Dropping of Load, E. J. Burnham.

Sleet and Ice on Transmission Lines, C. R. Oliver.

Electro-Mechanical Problem Analyzer, C. A. Nickle.

Losses in Iron Under the Action of Superimposed A-C. and D-C. Excitation, J. E. Jackson and O. E. Charlton.

MAY 7, 2:00 P. M.

ELECTRICAL APPARATUS SESSION

Tap Changing under Load, H. C. Albrecht.

Voltage Control Obtained by Varying Transformer Ratio, L. F. Blume.

Changing Transformer Ratios without Interrupting the Load, M. H. Bates.

Universal-Type Motors, L. C. Packer.

A Two-Speed Salient-Pole Synchronous Motor, R. W. Wieseman.

Short-Circuit Currents of Synchronous Machines, R. F. Franklin.

MAY 8, 10:00 A. M.

CABLES AND EDUCATION SESSION

Cooperative Course at the Massachusetts Institute of Technology, Prof. W. H. Timbie.

Oil-Filled Terminals for High-Voltage Cables, E. D. Eby.

Cable Joints, E. W. Davis and G. J. Crowdes.

Effect of Repeated Voltage Application on Fibrous Insulation, F. M. Clark.

Education on Industry, S. W. Ashe.

MAY 9, 10:00 A. M.

MEASUREMENTS SESSION

Calibration of Wavemeters, J. A. Stratton and Jas. K. Clapp.

Predetermination of Self-Cooled Oil-Immersed Transformer Temperatures, W. H. Cooney.

Studies of Time Lag of Needle Gaps, K. B. McEachron and E. J. Wade.

Recent Improvements in A-C. Indicating Instruments, S. H. Hoare.

Measurement of Electrical Output of Large A-C. Turbo-Generators, E. S. Lee.

Temperature Errors in Induction Watthour Meters, I. F. Kinnard and H. T. Faus.

Pacific Coast Convention at Seattle September 15

Good progress has been made in the plans for the next Pacific Coast Convention which will be held in Seattle, September 15-18. The local committee is already at work making arrangements and an excellent technical program is being planned.

The following convention committee has been appointed by President Osgood: Messrs. G. E. Quinan, Chairman, C. N. Beebe, Hiram W. Clark, Harry P. Cramer, E. J. DesCamp, W. C. DuVall, F. R. George, John Harisberger, C. A. Heinze, Joseph Hellenthal, Charles A. Lund, C. E. Magnusson, James S. McNair, C. E. Mong, L. W. W. Morrow and C. R. Wallis.

A. I. E. E. Meeting, New York, May 15, 1925

As previously announced, the annual business meeting of the A. I. E. E. will be held on Friday, May 15, at 8:15 p. m. (Daylight Saving Time), in the auditorium of the Engineering Societies Building, 33 West 39th Street, New York City. At this meeting the reports of the Committee of Tellers on the annual election of Institute officers and upon the proposed amendments to the Constitution, also the report of the Board of Directors for the year ending April 30, will be presented.

The session will continue for the consideration of "Steam Railway Electrification from the Executives' Standpoint." Addresses will be made by principal executives of manufacturing and railroad companies.

The national and New York Section officers are cooperating in the plans for this very interesting meeting, which will be somewhat unique and of great importance to electrical and railroad men alike.

Future Section Meetings

Baltimore

European Practises, by W. B. Potter, General Electric Co., May 15, 8:15 P. M.

Erie

The Telephone. May 19.

Electricity in Mining. June 16.

Fort Wayne

Annual Banquet. May 21.

St. Louis

Super-Power Systems. May 27.

Election of officers and Smoker. June 24.

Seattle

Baker River Development, by L. N. Robinson. Election of Officers. May 20.

Vancouver

Hydro-Electric Developments of the East Kootenay Power Company, by M. L. Wade. May 1.

Dinner and Annual Meeting for election of officers. June 5.

The St. Louis Spring Convention

APRIL 13-17, 1925

All anticipations for an enthusiastic and interesting meeting of the Institute in St. Louis were more than realized by the delegates and guests in attendance at the Spring Convention, April 13-17. The weather was generally propitious, except for some brief summer showers, and the season was unusually well advanced, even for that section of the country, so that the visitors enjoyed a week of typical June temperature.

The very efficient local committee under the chairmanship of Mr. B. D. Hull left nothing undone for the comfort and entertainment of those in attendance, and so carefully had plans been prepared that every feature of the convention functioned smoothly with a notable absence of the confusion frequently apparent in a less thoroughly organized meeting.

The Chase Hotel was also well adapted to the purpose of a convention as registration, information and other headquarters were grouped together at one end of the hotel lounge, and close to the meeting room for technical sessions. This proved advantageous in concentrating the activities to a single center as well as resulting in unusually good attendance at the technical sessions.

Ladies' Entertainment

Very ample provisions were made for the entertainment of ladies at the Convention and they were well represented. A special ladies' program was published scheduling all the events of the week which were of special interest to the ladies, and a ladies' headquarters was maintained on the first floor of the Chase Hotel, under the direction of Mrs. Herman Spoehrer; Here the visiting ladies were made acquainted with the local ladies. The ladies entertainment included visits to Country Clubs, luncheons, sightseeing tours, bridge parties, theatre parties, automobile trips, golf, dances, etc., all of which were well patronized and highly enjoyed.

Inspection Trips

The only scheduled inspection trip was on Wednesday afternoon when a large party visited the Cahokia generating station of the Union Electric Light & Power Co. This station was described and discussed at the first technical session of the Convention and this lent an added interest to the visit of inspection. The important features of the plant in which the visitors were chiefly interested were the pulverized fuel equipment, the vertically isolated-phase bus construction, the large turbo generators and the 132-kv. outdoor substation.

Many other informal inspection trips were made by various groups of visitors to the public utility plants in St. Louis and to the numerous industrial and manufacturing plants in the city and vicinity which were courteously thrown open for the inspection of the convention visitors. Transportation by automobiles was generously provided for the inspection parties by the Convention Committee.

Entertainment Features

On Monday evening an informal reception and dance was held in the Palm Room of the hotel; this was largely attended. Under the inspiration of an excellent orchestra and a large attendance of St. Louis ladies, dancing was enjoyed until a late hour.

On Wednesday evening a smoker was held in the Palm Room which was filled to capacity. A considerable variety of vaudeville entertainment was enjoyed during the early part of the evening, but the climax of the entertainment was reached in a "mock trial" in which President Osgood was charged with felonious assault with intent to kill upon his caddy on the golf links. Three members of the St. Louis bar acted as judges, prosecuting attorney and attorney for the defense, respectively, and the examination of the jurors and depositions of witnesses gave rise to highly amusing dialog most of which was necessarily impromptu. The defendent was found guilty by the jury, but he refused to stand up to be sentenced and as the court could not sentence a prisoner while he was seated, the case was dismissed and the court adjourned.

On Thursday evening a banquet and dance was held in the Palm Room in which a number of novel features were introduced. Brief remarks by several of the officers were alternated by vaudeville acts and dancing. The speaker of the evening was Doctor F. B. Jewett, who gave an interesting talk on the "Present Aspects of Electrical Communication." At the close of Doctor Jewett's remarks, the tables were removed and dancing continued for the remainder of the evening.

Games and Sports

There were numerous games of golf, putting contests, bridge, etc., played during the Convention and for these prizes were awarded, the prize winners in the various games being as follows:

Golf—Men's golf prize, a demi tasse set to Mr. C. H. Giroux.

Bridge—First prize to Mrs. G. C. Vahrenhold, gold wrist watch presented by the Moloney Electric Company; second prize to Mrs. H. S. Sherman, electric waffle iron presented by the Laclede Gas Light Company; third prize to Mrs. T. O. Maloney, electric flat iron presented by the Western Electric Company; fourth prize to Mrs. H. W. Eales, electric fan presented by the Wagner Electric Company; fifth prize to Mrs. R. A. Lea, electric iron presented by the Commercial Electrical Supply Company.

Putting Contest—First prize to Miss Ruth Moloney, bridge lamp, presented by the Union Electric Company; second prize to Mrs. Stanley Stokes, boudoir lamp presented by the Gross Chandelier Company; third prize to Mrs. G. A. Waters, electric toaster presented by the McGraw Company; fourth prize to Mrs. E. D. Schutt, curling iron presented by the Wesco Supply Company; fifth prize to Mrs. Herbert Young, baby lamp presented by the St. Louis Brass Company.

Technical Sessions

The technical sessions were well attended and the general interest in the papers was reflected in the discussions which were largely prepared in advance and showed careful consideration of the papers on the part of the speakers. President Osgood presided at all sessions, assisted by various members of the technical committees in handling the discussions. The papers and discussions at the several sessions are given below.

Monday Afternoon

The first session was called to order by Vice-president H. W. Eales, who extended a warm welcome to the visiting delegates, after which Mr. B. D. Hull gave some brief instructions in regard to various trips of inspection and excursions. Secretary F. L. Hutchinson was then called upon for a few remarks in the course of which he announced that the Institute membership had recently passed the 17,000 mark. President Osgood then took the chair and welcomed the assembled delegates and gave a short talk on the duty of the engineer in making his voice heard in those civic affairs in which he is eminently qualified to take a leading part. He then called on Mr. Hirshfield to present his paper on the *Trenton Channel Station.* This was followed by brief descriptions of the Philo Station of the Ohio Power Com-

pany, by E. H. McFarland, Weymouth Station of the Edison Electric Illuminating Company, by I. E. Moultrop, and the Cahokia Station of the Union Electric Light & Power Company, by H. W. Eales. A long discussion on power-plant design followed by Messrs. Earl Hopping, F. A. Sheffler, C. G. Spencer, E. H. Tenney, H. R. Woodrow, H. W. Brooks, R. H. Summerhayes, Louis Elliot, K. McH. Irwin and closure by C. F. Hirshfeld.

Tuesday Morning

The second technical session on the general subject of power systems, under the auspices of the Protective Devices Committee, was called to order Tuesday morning and four papers were presented in abstract as follows: *Interconnection of Systems with Frequency Changers*, by H. R. Woodrow; *Eight Years' Experience with Protective Reactors*, by James Lyman, L. L. Perry and A. M. Rossman, read by Mr. Rossman; *Mississippi River Crossing of Crystal City Transmission Line*, by H. W. Eales and E. Ettlinger, read by Mr. Eales; and *Application of Automatic Control to Substation Apparatus*, by W. H. Millan. These papers were discussed as a group, with Mr. Woodrow in the chair, by James Lyman, H. W. Eales, F. L. Stone, H. R. Summerhayes, H. W. Osgood, Chester Lichtenberg, S. I. Oesterreicher, F. H. Kierstead, R. W. Wieseman, E. K. Huntington, with closures by H. R. Woodrow, A. M. Rossman and E. Ettlinger.

Tuesday Afternoon

The third technical session on the general subject of electrical machinery was held under the auspices of the Committee on Electrical Machinery, and the first paper to be presented was on *Initial and Sustained Short Circuits in Synchronous Machines*, by V. Karapetoff. This was followed by the presentation of papers on *Short-Circuit Currents of Synchronous Machines*, by R. F. Franklin, *A Two-Speed Salient-Pole Synchronous Motor*, by R. W. Wieseman, and *Self-Excited Synchronous Motors* by J. K. Kostko, read by Prof. W. L. Upson.

This group of papers was discussed by Messrs. S. H. Mortensen R. E. Doherty, F. H. Kierstead, H. Weichsel, V. Karapetoff, R. W. Wieseman, Val Fynn, with closures by Messrs. Karapetoff, Franklin and Wieseman.

Wednesday Morning

The fourth session was devoted to the subject of electrical communication under the auspices of the Committee on communication, four papers being presented as follows: *A New Type of Hornless Loud Speaker*, by C. W. Rice and E. W. Kellogg, read by Mr. Kellogg; *Communication in Railroad Operation*, by I. C. Forshee; *Echo Suppressors for Long Telephone Circuits*, by A. B. Clark and R. C. Mathes, read by Mr. Clark; and *Frequency Multiplication*, by N. Lindenblad and W. W. Brown, read by Mr. Brown.

The discussion on this group of papers was participated in by Messrs. H. A. Frederick, S. P. Shackleton, H. S. Foland, B. F. MacNamee, V. E. Thelin, E. W. Kellogg, C. H. Gaffeney, R. S. Glasgow and C. E. Rogers. Closures were made by Messrs. Kellogg, Forshee and Clark.

Thursday Morning

The fifth session on the subject of marine applications of electricity was held under the auspices of the Committee on Applications to Marine Work. Three papers were presented at this session, viz.: *Historical Review of Electrical Applications on Shipboard*, by H. L. Hibbard and Wm. Hetherington, read by Mr. R. A. Beekman, *The Electrical Engineer in the Merchant Marine*, by G. A. Pierce, read by Mr. W. E. Thau; and *Electrical Ship Propulsion*, by H. F. Harvey and W. E. Thau, read by Mr. Thau.

With Mr. Beekman in the chair, discussion followed by Messrs. F. A. Sheffler, V. Karapetoff, A. W. Berresford, C. H. Giroux, A. A. Coyle, A. B. Homer, G. F. Klugmann, and R. H. Beekman. Closures were by Messrs. Beekman and Thau.

Friday Morning

The sixth session was devoted to mining subjects, in addition to papers on automobile lighting and a pathological vibration recorder respectively, the session being under the auspices of the Committee on Applications to Mine Work. These papers were as follows: *Coal Mine Electrification*, by W. C. Adams, *Application of Motors to Mine Locomotives*, by W. A. Clark, *Electric Shovels*, by D. J. Shelton and D. Stoetzel, read by Mr. Stoetzel; *Automobile Lighting*, by J. H. Hunt; and *A Vibration Recorder for Pathological Analysis*, by C. I. Hall.

Mr. F. L. Stone presided during the discussion by Messrs. Carl Lee, W. M. Hoen, R. N. Felge, R. A. Beekman, L. C. Porter, W. D'A. Ryan, C. L. Mathews, E. J. Shelton, J. H. Hunt, with closures by Messrs. Adams, Clark, Hunt and Hall.

Friday Afternoon

The seventh and last technical session of the convention was devoted to the subject of industrial power applications, under the auspices of the Committee on General Power Applications. Five papers were presented as follows: *Load Building Possibilities of Electric Heating*, by C. L. Ipsen; A High-Frequency *Induction Furnace Plant for the Manufacture of Special Alloys*, by P. H. Brace; *Electrically-Heated Lead, Solder and Babbitt Pots*, by J. C. Woodson; *Synchronous-Motor Drive for Rubber Mills*, by C. W. Drake, read by A. S. Rufsvold; and *Use of Purchased Power in Glass Manufacturer*, by A. L. Harrington.

These papers were discussed, with Mr. L. W. W. Morrow in the chair, by H. S. Mortensen, Mr. Haines, N. H. Shaw and Graham R. Gosrean.

* * * * * * * *

At the meeting of the Board of Directors at St. Louis the following resolution was unanimously adopted:

Resolved: That the Board of Directors of the American Institute of Electrical Engineers, meeting in St. Louis, April 14, during the annual Spring Convention, hereby expresses on behalf of the members in attendance, its hearty appreciation of the effective services of the members of the General Convention Committee and their associates in making and carrying out with marked success the plan for the comfort and convenience of the members and guests in attendance.

The personnel of the Spring Convention Committee was as follows: B. D. Hull, *Chairman*, H. W. Eales, *Vice-Chairman*, J. Harrison, *Secretary*, Edward Bennett, H. E. Bussey, J. M. Chandlee, C. H. Kraft, L. W. W. Morrow, C. P. Potter, W. L. Rose, H. S. Sands.

A. I. E. E. Directors Meeting

A meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the Hotel Chase, St. Louis, on Tuesday, April 14, 1925.

There were present: President Farley Osgood, Newark, N. J.; Past President F. B. Jewett, New York; Vice-President H. W. Eales, St. Louis; Managers J. M. Bryant, Austin, Tex., and Ernest Lunn, Chicago; Secretary F. L. Hutchinson, New York; by invitation, Past President A. W. Berresford, Niagara Falls.

The Board ratified the approval by the Finance Committee of monthly bills amounting to $30,198.46.

A report was presented of a meeting of the Board of Examiners held April 6, and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 68 Students were ordered enrolled; 231 applicants were elected to the grade of Associate; 6 applicants were elected to the grade of Member; 5 applicants were transferred to the grade of Member.

As requested by the A. E. S. C., the Board voted to approve the admission of the American Mining Congress to membership in the American Engineering Standards Committee.

President Osgood announced the receipt of a telegram from Vice-President J. E. Macdonald, of Los Angeles, advising of the

death, on April 10, of former Vice-President James A. Lighthipe, Chief Electrical Engineer, Southern California Edison Company. The Board adopted a memorial resolution, which is published elsewhere in this issue.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

President Coolidge Appoints Muscle Shoals Commission

On March 27th President Coolidge named a Commission of five men who are to examine into and report to him upon the most practical method of utilizing Muscle Shoals. The Commission is expected to make a comprehensive study of the entire project. And the appointment was made in compliance with the Madden resolution adopted by the House of Representatives at its last session. The Commission will be composed of former Representative John C. McKenzie of Illinois, former Senator Nathaniel B. Dial of South Carolina, Professor Harry A. Curtis of Yale and William B. McClellan of New York, Past President of the A. I. E. E.

Mr. McClellan, who was President of the Institute during the administrative year 1921-22 was born in Philadelphia, Pa. He graduated from the University of Pennsylvania in 1900 and after graduation was engaged with the Philadelphia Rapid Transit Commission until 1905 when he went with Westinghouse, Church, Kerr and Company in electrification work on railways. In 1907 he became associated with H. T. Campion in construction work as member of the firm of McClellan and Campion. Just before the war Mr. McClellan was Dean of the Wharton School of Finance of the University of Pennsylvania. In 1919 he was made Vice President of the Cleveland Electric Illuminating Co. He is now a member of the firm of McClellan and Junkersfeld, New York.

A Memorial to Doctor Steinmetz

As a memorial to Doctor Steinmetz, the Schenectady Section of the A. I. E. E. is initiating a series of annual lectures to be known as "The Steinmetz Lectures."

It is the intention of the Section to include in this course, lectures on the various aspects of science and engineering presented by recognized leaders in the field. The first lecture of the series will be presented on May 8th by Doctor M. I. Pupin, of Columbia University, the subject being "Law, Description and Hypothesis in the Electrical Science." It will treat of the dynamic laws, the rules in accordance with which bodies react against electrical forces, and the hypothesis by means of which the scope of the electrical laws was extended beyond the limits of experiments which formulated them. Such a subject as this, constituting a review of the steps of development of electrical science from the researches of Faraday and Maxwell to the most recent of modern advances, is particularly fitting for the first lecture of the series in view of the many contributions made to this very development by Doctor Steinmetz, himself.

Testimonial Dinner to Edward Dean Adams

The friends of Edward Dean Adams, men prominent in the fields of engineering, science, art, literature, transportation, finance, industry and club life, tendered him a testimonial dinner at the Hotel Waldorf Astoria, Thursday evening, April 9, 1925, on his seventy-ninth birthday. Through many of the activities to which Mr. Adams has so effectively devoted his life, he has rendered conspicuous services to the engineering profession and industry. For years he has been a member of the Institute, exceedingly helpful in many of its activities. He has represented the A. I. E. E. upon the Library Board of the United Engineering Society and for five years was an active member of the Edison Medal Committee, serving as Chairman during the years 1922-1924.

During the dinner, Doctor W. F. Durand, President of the American Society of Mechanical Engineers, was in the chair. Speeches appreciative of Mr. Adams career were by Mr. A. Monro Grier, President of the Canadian Niagara Power Company, and by Mr. William Nelson Cromwell. Letters of congratulations also were read from Canada, England, France and Germany, beside many from the United States. An illuminated testimonial was presented to Mr. Adams signed by the Dinner Committee and a number of intimate friends. Mr. Adams made a very appropriate response to the honors paid him.

John Fritz Medal Presented to John F. Stevens

At a joint meeting of the four Founder Societies, Civil, Mechanical, Mining and Electrical Engineers, on the evening of Monday, March 23, 1925, the John Fritz Medal for 1925 was presented to John Frank Stevens for his great achievements as a civil engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern Railway. John R. Freeman, past-president of the A. S. C. E. and A. S. M. E. presided. The presentation was made by Charles F. Rand, past-president of the A. I. M. E. Addresses were made by Ralph Budd, president of the Great Northern Railway Company and Roland S. Norris, former ambassador to Japan.

The John Fritz Medal is awarded annually by a board of four representatives of each of the four national engineering societies for notable scientific or industrial achievements, regardless of nationality or sex. The medal was established by professional associates and friends of John Fritz on his eightieth birthday, August 21, 1902. The A. I. E. E. representatives on the present Board are Farley Osgood, Wm. McClellan, Frank B. Jewett, Harris J. Ryan.

A pamphlet containing an account of the presentation exercises, including the addresses delivered, will be available in a short time, and a copy may be had, without charge, by addressing the John Fritz Medal Board of Award, 29 West 39th St., New York.

Comments Requested on Preliminary Drafts of Standards

In the progress of the work of the revision of the A. I. E.E. Standards, three more sections of the standards have been brought by the working committees to a point where the comments of the general Institute membership are desired. These sections are as follows:

No. 11—Railway Motors.
No. 30—Wires and Cables.
No. 33—Electrical Measuring Instruments.

These drafts of standards have been prepared by working committees in whose appointment every effort has been made to select the men from all branches of the art most competent to contribute directly to the development of an accurate and generally acceptable set of standards. Copies of each of the three reports noted above are now available, without charge, and all who are interested are requested to apply for copies to Institute Headquarters.

In order that these reports may be revised and adopted as Institute Standards this Spring, it will be necessary for all comments to be sent in at once.

A Reference Guide for Students and Engineers

A small, convenient-sized pamphlet, entitled "Where to Seek for Scientific Facts," has recently been compiled by Alec B. Eason, (M. A. Cantab.), A. M. I. C. E., A. M. I. E. E., supplying

a valuable reference for technical information to those interested in such bibliographical arrangement.

The several chapters into which the contents are divided are (1) Searching for Books; (2) Searching for Periodicals; (3) Bibliographies and Abstracts, and (4) Suggestions, covering, respectively information as to where to find lists of books on various scientific subjects; books, journals and proceedings, transactions and bulletins of learned and scientific societies; indexes of literature and publications and papers on technical and scientific subjects, and abstracts of technical papers. The publishers are S. Rentell & Company, Ltd., 36 Maiden Lane, W. C. 2, London, and the price is one shilling, net.

Insulator Test Specifications

A CORRECTION

With references to Insulator Test specifications as published in the March issue of the JOURNAL (page 300); a section which was omitted from the report as originally submitted is given below.

IX—OPTIONAL TESTS—SUSPENSION INSULATORS

1. *Thermal Test.* After the routine "Test After Assembly" a number of representative assembled insulators shall be subjected to a "Thermal Test." Specifications for this test shall be the same as the specifications for the "Thermal Test" on pin insulator shells, except that the word "unit" shall be substituted for the word "shell."

Missouri School of Mines and Metallurgy Organizes Student Branch

An A. I. E. E. Student Branch has been organized at the Missouri School of Mines and Metallurgy. The official authorization for the Branch was made on March 13th.

The officers who have been elected are T. C. Adcock, Chairman; J. D. Behnke, Secretary, and I. H. Lovett, Faculty Advisor. At the time of organization there were fifteen members of the Branch.

College of the City of New York has Latest Branch

A new Branch of the Institute was organized on April 2nd at the College of the City of New York. Twenty-two students of electrical engineering formed the first list of members.

The officers elected were as follows: Chairman, Sidney E. Gottschall; Vice-Chairman, Daniel D. Schneeweis; Secretary, Frank Kulman; Treasurer, A. Weinberg; Manager of Publicity, Benjamin Orange.

This is the most recently formed Branch of the Institute and it is the 82nd Student Branch to be organized.

A. I. E. E Year Book

The A. I. E. E. 1925 Year Book is available to members without charge upon application to the Secretary, 33 West 39th Street, New York, N. Y.

The book contains an alphabetical and geographical listing of the membership, revised to January 1, 1925; also the Constitution, By-Laws, lists of Officers and Committees, as well as much other information relating to the activities of the Institute.

Spring Meeting of the American Society of Mechanical Engineers

The tentative program for the Spring Meeting of The American Society of Mechanical Engineers, to be held this year at Milwaukee, Wisconsin, May 18-21 inclusive, offers much of both technical and social attraction. Many subjects of keen national interest, although possibly only semi-technical in nature, such as Forest Products, National Defense and the handling of materials will receive both written and oral treatment. With a representative attendance, much should be accomplished toward valuable progress along the lines scheduled for both general and specific betterment. Excursions in which no doubt many will participate, have also been planned for both diversive and instructive purposes.

Summer Meeting of Civil Engineers

Salt Lake City, Utah, located in the center of a summer playground, is the place chosen by the American Society of Civil Engineers for their Summer Meeting, July 8-10, 1925.

The program will be devoted largely to reclamation subjects, with an opening session on Irrigation Development, Financing Land Settlement, Irrigation and Power Development and similar matters.

In the immediate vicinity of the city are many places of interest to visitors, among which are the great open-cut copper mines at Bingham, Utah, the Great Salt Lake, Mount Timpanogas with its cave, and improved automobile highways and railroad routes leading to the Yellowstone and Glacier National Parks, Mount Lassen, Creter Crater Lake, Yosemite, etc., etc.

The natural and planned attractions should guarantee a most successful and enjoyable time for all who attend.

AMERICAN ENGINEERING COUNCIL

ADMINISTRATIVE BOARD TO MEET AT PHILADELPHIA

The Administrative Board of the American Engineering Council, will meet in Philadelphia, May 8 and 9 to formulate plans for the elimination of waste in the administration of the vast public works functions of the United States Government, and to unify national reforestation effort.

Engineers of local and national societies in all parts of the country will attend. "It is the conscious policy of the Council," said the announcement, "to attack waste wherever found within the sphere of the engineer, and to bring to public attention the duty resting upon employer and employee alike to wipe it out.

"The Council is adhering to the plan originated by Secretary Herbert Hoover, who, as first president of the Council, instituted the nationwide engineering assay of waste which revealed heavy avoidable losses to industry. The Council purposes to support the Jones-Wyant measure pending in Congress to reorganize the Department of the Interior with a view of accomplishing greater economies and efficiency.

"The Council's Committee on Government Reorganization as it Relates to Engineering Matters has devised a concrete proposal of departmental organization which, it is believed, meets the demands of sound public policy. This proposal will be publicly discussed at the meeting of the Board to be held under the auspices of the Engineers Club of Philadelphia in May."

The Council, of which Honorable James Hartness, of Vermont is president, has sent to its member organizations throughout the country a request to aid in the observation of American Forest Week, which President Coolidge has proclaimed for April 27-May 3. Engineers in every state are expected to cooperate.

F. K. Copeland of Chicago, it was announced, has been appointed chairman of the Council's Committee on Elimination of Waste in Industry. Other members are:

Secretary Herbert Hoover, U. S. Department of Commerce; Dean Perley F. Walker, University of Kansas; R. E. Flanders, Springfield, Vermont; C. C. Thomas, Los Angeles; W. P. Hunt, Moline, Ill.

The council, it was stated, will cooperate closely with the Department of Commerce and other agencies in carrying out the purposes of the recent round table conference held under the direction of the National Civic Federation in New York.

American Engineering Standards Committee

FORMATION OF ADVISORY COMMITTEE ON STANDARDIZABLE WORK

That American business, big and little, is organizing to put all its power and prestige back of the standardization movement, and to facilitate and expedite an extensive, nationwide work is announced by the American Engineering Standards Committee.

The first step in this campaign to give impetus to the united industrial effort against waste and for the quickening of trade is the formation of a committee of five first-line executives, to act as an advisory body to the American Engineering Standards Committee. This advisory committee will consist of the following: J. A. Farrell, president of the U. S. Steel Corporation; G. B. Cortelyou, president of the Consolidated Gas Company, New York; J. W. Lieb, vice-president of the New York Edison Company; L. F. Loree, president of the Delaware & Hudson Company, and Gerard Swope, president of the General Electric Company.

Scope of Committee

In focussing the united influence of big industries of national and international ramifications on the American Engineering Standards Committee program, the committee of five just formed will emphasize what is regarded as the fundamental principle of standardization: That standardizing must facilitate and stimulate, and not hinder industry.

The committee will assist in keeping executives in touch with the national movement in its development, in extending its influence and support both intensively and extensively among industrial groups, bringing about the fullest cooperation along right lines in standardization work, between industry and government and particularly in the solution of the problem of industrial waste, into which Secretary Hoover has thrown the resources of the Department of Commerce.

Hitherto the movement has been largely centered in and carried on by the technical man. The appointment of this committee marks definite recognition of the fact that standardization has now become a managerial problem of the first rank in industrial production distribution and utilization, and as such, deserves the fullest industrial support.

The American Engineering Standards Committee, organized in 1918, has been engaged in standardizing work on a national basis since that time, representing a membership of 34 national organizations, including nine engineering societies, 18 industrial associations, and seven departments of the Federal Government. It serves primarily as a national clearing house for engineering and industrial standardization. With the purpose of coordinating standardization work in the individual industries, effected by associations, societies and governmental agencies, into a unified system of national standardization.

Significant is the fact that approximately 250 organized trade, technical, industrial and governmental bodies are cooperating with the American Engineering Standards Committee, and have about 1200 accredited representatives on its various working subcommittees. This extensive participation in the Committee's work seems to assure the acceptance and actual adoption of the national standards thus worked out and approved. To date, some 170 standardization projects are actively under either development or have reached the stage of approved standards.

This new plan to intensify the national standardization movement by lending the American Engineering Standards Committee the support of the advisory committee representing as many of the largest industrial interests in the country, had its inception at a dinner given by J. A. Farrell, president of the U. S. Steel Corporation, John A. Freeman, vice-president, Manufacturers Mutual Fire Insurance Company, Guy E. Tripp, Chairman and E. M. Herr, president of the Westinghouse Electric & Manufacturing Company, attended by thirty industrial leaders, among whom were, Walter R. Addicks, Vice-President, Consolidated Gas Company; M. W. Alexander, Managing Director, National Industrial Conference Board; W. W. Atterbury, Vice-President, Pennsylvania Railroad; Willis Booth, President, International Chamber of Commerce; John A. Coe, President, American Brass Co.; C. P. Coleman, President, Worthington Pump & Machinery Co.; Edward J. Cornish, President, National Lead Company; Geo. B. Cortelyou, President, Consolidated Gas Company; J. M. Davis, President, Manning, Maxwell & Moore; Henry L. Doherty, President, Henry L. Doherty & Co.; Col. John H. Finney, Mgr. Washington Office, Aluminum Company of America; Norman J. Gould, President, The Goulds Manufacturing Company; Bancroft Gherardi, Vice-President, American Telephone & Telegraph Company; Dr. Frank B. Jewett, Vice-President, American Telephone & Telegraph Company; Robert Lamont, President, Steel Foundries Corporation; J. W. Lieb, Vice-President, New York Edison Company; L. F. Loree, President, Delaware & Hudson Company; James H. McGraw, President, McGraw-Hill Company; E. J. Mehren, Vice-President, McGraw-Hill Company; Frank W. Smith, Vice-President, United Electric Light & Power Company; L. S. Storrs, President, The Connecticut Company; Charles B. Seger, President, United States Rubber Company; A. A. Stevenson, Vice-President Standard Steel Works Company; Gerard Swope, President, General Electric Company; A. W. Whitney, Associate General Manager, National Bureau of Casualty & Surety Underwriters; C. E. Skinner, Chairman, American Engineering Standards Committee; and P. H. Agnew, Secretary, American Engineering Standards Committee.

PERSONAL MENTION

Charles R. Poe, has left New York City and the services of the American Telephone and Telegraph Company to join the Northwestern Bell Telephone Company, Omaha, Nebraska.

C. Otto von Dannenberg has resigned from the J. G. White Engineering Corporation to enter the field organization of Messrs. Sanderson & Porter of New York, at Springdale, Pa.

J. C. Carney is now representing the Star Electric Motor Company of Newark, N. J., as Sales Engineer, having severed his connections with the Cutler Hammer Manufacturing Company.

Frank M. Reeves is now with the Engineering Department of the Gedge-Gray Company, Lockland, Ohio, as Development Engineer, instead of with the Radio Company of Columbus, Ohio.

Berg V. Thor has been transferred by the Westinghouse Electric & Mfg. Company, from the Service Department of their Chicago Branch to represent their Service Department in the Milwaukee District.

Justin Lebovici has resigned from his position as Chief Engineer of the Triumph Electric Company, Cincinnati, Ohio, to accept new work as Electrical Engineer for the Otis Elevator Company, New York City.

Charles F. King, Jr., has left the service of the Pennsylvania Railroad System to take a position in the General Engineering Department of the Westinghouse Electric & Mfg. Company, Pittsburgh, Pa.

A. E. Asklund, previously Electrical Engineer with the Texas Power & Light Company, Dallas, Texas, will now be identified

with the Westinghouse Electric & Mfg. Company of East Pittsburgh, Pa., as switchboard engineer.

C. F. Terrell, who was Superintendent of Light and Power for the Puget Sound Power and Light Company, Bellingham, Washington, is now engaged in like service for the El Paso Electric Railway Company, El Paso, Texas.

H. M. Van Gelder has recently been chosen Electrical Engineer for the Department of City Transit in Philadelphia, and will have charge of the electrical equipment of the new subway now under construction in that city.

A. O. Admire, who has for many years been working in many States and varied capacities for the Goodyear Tire & Rubber Company, has been transferred from the South Carolina office to Louisiana, with company offices at Shreveport.

Julian C. Bailey has been made Superintendent of the Testing and Motor Laboratory of the Gulf States Steel Company, Gadsden, Alabama. Mr. Bailey was previously with the Westinghouse Electric & Mfg. Company at East Pittsburgh.

Gordon H. Gildersleeve, Sales Engineer for the General Electric Company, New York City, has been appointed Dist. Manager, Cleveland, Ohio, for the Cutter Electrical & Mfg. Company, whose head office and works are at Philadelphia.

R. M. Coleman, who for many years has been Manager of the Electrical Department of Fairbanks, Morse & Company, New York City, has withdrawn to open offices of his own under the name of R. M. Coleman Company, Long Island City, New York.

Kenneth B. Aldrich, formerly Electrical Engineer for the Puget Sound Power & Light Company, Tacoma, Washington, has opened consulting engineering offices with Mr. B. W. Kibler, Dean of the Trade Engineering Department, City College, Tacoma.

Franklin R. Speer, who has been engaged in the activities of the Scranton Electric Company, Scranton, Pa., has been transferred by the parent organization, the American Gas and Electric Company, to the Bridgeton office of the Electric Company of New Jersey.

Arthur L. Dow, after a sojourn in Clearwater, Fla., to recover his health, has decided to open his own offices there. Mr. Dow was with the Hydraulic Division of the Department of Engineering and Construction of Stone & Webster, Boston, Massachusetts.

Jose A. Racaj, following a ten months' stay in Spain, has returned to the United States to join the S. A. Rapier Company, New York City, as Assistant Sales Manager. Mr. Racaj was, before, identified with the General Electric Company, Schenectady, New York.

Earl R. Witzel, Laramie, Wyoming, has completed the special teaching work which he was doing in the Engineering Department of the University of Wyoming, and has entered the Engineering Department of the Mountain States Telephone & Telegraph Company, Denver, Colorado.

Theodore I. Jones, former sales agent for the Brooklyn Edison Company, has been elected Vice-President and General Manager of The Radwill Company, The Pneumelectric Corporation and The American Flexible Shaft Manufacturing Corporation, with executive offices at 20 Broadway, New York City.

Herbert N. Fairbanks has become Superintendent of Telephones for the Broward Utilities Company, Hollywood, Fla., where they are now constructing a new 2500-line exchange to accommodate the new City of Hollywood, service for which will be established this fall. Mr. Fairbanks was previously located at Miami, Fla.

R. C. L. Greer, for the past three years Resident Engineer for the East Penn Electric Company, Pottsville, Pa., has now been made General Superintendent of the Portsmouth Power Company, Portsmouth, N. H. This Company was recently taken over by the Associated Gas & Electric Company and is being made a part of their system.

Talmadge Conover, who until recently was with the Puget Sound Power & Light Company, Seattle, Washington, is now assistant to the Superintendent of the Transportation Department of the Puget Sound Electric Railway, the Tacoma Railway & Power Company and the Park Auto Transportation Company, at Tacoma.

Oscar Weinreb, Electrical Engineer for the Acme-International X-Ray Company, has returned from a thirteen months' trip in Argentine, Uruguay and Brazil, to the Company's Chicago office. Mr. Weinreb, during his travels, made scientific study a part of his work while establishing new South American connections for his company.

E. G. Jocey, who was with the New England Oil Refining Company, Fall River, Mass., is taking a position as Electrical Engineer for the oil refining works of the Bethlehem Steel Company, now being constructed by them for the Argentine government at La Plata. Mr. Jocey's headquarters will be with the Bethlehem Steel Company at Buenos Aires.

Arthur S. Kirk, who until recently was with Messrs. Stone & Webster of Boston, has made new connections with the Blackstone Valley Gas & Electric Company, of Pawtucket, R. I.

T. S. Bindshelder has recently been appointed Chief Electrical Engineer of the Burroughs Adding Machine Company, Detroit, Mich.

Roy L. Shipp, who was superintendent for the Guanajuato Power Company, Guanajuato, Mexico, has accepted the position of Manager for the Cia de Luz Electrica y Fuerza Motriz de Orizaba, Orizaba, Vera Cruz.

Rene P. Boulassier, who for the past year has been Manager of the Taximetre Company, Mecanique de Recision, in Paris, is now connected with Levois at Moses, Patent Agents as consulting engineer.

Charles E. Stephens has been appointed Manager of the New York office of the Westinghouse Electric & Mfg. Company, Mr. Stephens has been connected with the Westinghouse Electric & Mfg. Company since 1900, and since 1917, when he was made Manager of the Supply Dept., has been serving in the New York office of the Company. His first connection was with the Company works at East Pittsburgh.

James C. Clark has resigned his position as professor in charge of Electrical Engineering research at Iowa State College, to join the Sales Engineering Staff of the Pacific Electric Manufacturing Company of San Francisco, designers and builders of oil circuit breakers and other high-voltage line equipment. Mr. Clark has been identified with the high-voltage research carried on at Stanford University for the past twelve years and has had a varied and extensive experience in practise.

Clarence Herbert Sanderson, of the engineering staff of the New York Edison Company, has been appointed Assistant Electrical Engineer of that company, succeeding R. H. Tapscott, who has assumed the duties of Electrical Engineer. Mr. Sanderson entered the employ of the New York Edison Company in 1920, when he was given the position of assistant to the Chief Electrical Engineer. His work covered specifications, design, purchasing, and the supervision of operation, maintenance, and repairs. He came to New York from the Havana Electric Railway, Light, and Power Company, where, as Chief Electrical Engineer and later Assistant Chief Engineer, he had installed a 50,000-kv-a. steam turbine plant, having reorganized and modernized most of that company's technical departments. For ten years prior to joining the Havana Company, Mr. Sanderson was in the engineering department of the Westinghouse Electric & Manufacturing Company, specializing in switchboard and power station design. He is a native of Illinois and a graduate of Ohio State University. For five years, while with the Westinghouse Company, he was instructor in mathematics at the

Carnegie Institute of Technology. He became a Fellow of the American Institute of Electrical Engineers in 1918, and has served on numerous technical committees both for the Institute and the National Electric Light Association.

Obituary

James A. Lighthipe, Chief Electrical Engineer, of the Southern California Edison Company, died of pneumonia in Los Angeles, California, April 10, 1925. Mr. Lighthipe was born in Orange, New Jersey, in the year 1857 and in 1879 became one of the group of men Edison gathered about him at his laboratory in Menlo Park. In the Fall of that year Mr. Edison sent him abroad, where he remained five years engaged with the Edison Telephone Company in London, and the Edison Company in Paris and Berlin. On his return to the United States in 1884 he engaged in the installation of Brush arc lighting sets, was made superintendent of construction of the Edison Consolidated Electric Company which was merged into the Edison General Electric Company and later the General Electric Company. He acted as district engineer of the General Electric Company at their San Francisco office until 1908, when he became electrical engineer for the Edison Electric Company of Los Angeles. Mr. Lighthipe was not only an electrical engineer, but mechanical and civil engineer as well. His judgment and personal character were such that his opinions were accepted by consumers as the opinion of an independent consulting engineer.

He became an Associate of the Institute in 1894 and a Fellow in 1913. From 1913 to 1915 he served as Vice-President. At the meeting of the Board of Directors of the Institute held in St. Louis, Mo., on April 14, 1925, the following resolution was adopted.

Resolved: That the Board of Directors of the American Institute of Electrical Engineers, in session at the Spring Convention in St. Louis, Missouri, April 14, 1925, hereby expresses its sense of the loss which has been sustained by the entire membership of the Institute through the death of James A. Lighthipe, Chief Electrical Engineer of the Southern California Edison Company, and former Vice-President of the Institute. In Mr. Lighthipe's long association with the electrical industry from the pioneer days of 1879 in the Edison Laboratories at Menlo Park, down through his last work with the Southern California Edison Company, his character and judgment endeared him to all with whom he came in contact.

Be it further Resolved: That the Board of Directors, speaking for the entire membership, hereby expresses its sincere sympathy to the members of Mr. Lighthipe's family, and directs that this resolution be spread on the records of the Institute and published in its Journal.

Lafayette Boyd Hedges, of San Pedro, California, Associate of the Institute, met death March 24th, 1925 as the result of a fall from a ladder, causing concussion of the brain. Mr. Hedges joined the Institute in 1916. Born at Citronella, Alabama, September 8th, 1876, his early education was through the local grammar school, with three years at the Barton Academy High, Mobile, Ala. Finishing there in 1892, Mr. Hedges took a position with the Postal Telegraph Co. but returned to studies in 1904 to the College preparatory in Chicago, where he finished in 1905 to pursue his engineering course with four years at Massachusetts Institute of Technology where he won his S. B. degree. His engineering work has been with the United Wireless Telegraph Co., Maintenance, Wisc., the Western Union Telegraph Company of Springfield, Mo., as Solicitor of the Utah Light and Railway Company, Salt Lake City, Utah, and Chief Electrician of the Ely Light and Power Company, East Ely, Nev.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES APRIL 1-30, 1925

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the texts of the book.

All the books listed may be consulted in the Engineering Societies Library.

Theoretical and Applied Electrochemistry.

By Maurice De Kay Thompson. Revised edition. N. Y., MacMillan Co., 1925. 551 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.50.

This volume consists of a revision of the author's "Applied Electrochemistry," with an added treatise on theoretical chemistry. The theoretical section is designed to include, without excessive length, all the theory that will be of interest to an electrochemical engineer. The remainder of the book gives an account of the most important electrochemical industries, and the applications of electrochemistry in the laboratory. It is divided into the applied electrochemistry of aqueous solutions, and electric furnaces and their products. Electroplating, the electrolytic extraction and refining of metals, electrolytic oxidation and reduction, the electrolysis of alkali halides and water, storage cells, electric furnaces and electrothermic processes are discussed.

Railway Electrification.

By H. F. Trewman. Lond. & N. Y., Isaac Pitman & Sons, 1924. 244 pp., illus., diagrs., tables, 9 x 6 in., cloth. $7.50.

The object of the author is to present to serious students of railway engineering a number of the various problems encountered in electrification, with especial reference to the financial aspect. Discusses the manufacture and transmission of electricity, its conversion and distribution, railroad motors, energy consumption, suburban and trunk line traffic.

RAILROAD OPERATION.

By Ernest Cordeal. N. Y., Simmons-Boardman Publishing, Co., 1924. (Railwaymen's handbook series). 255 pp., illus. 7 x 5 in., cloth. $2.00.

The aim of the author is to bring to the attention of young men in railroad work certain principles of management which apply to most railroads and to show the results which have been attained by their application. The book does not attempt to outline an exact system; it is intended to induce young operating men to study their problems intensively and to assist them in the solution of the problems of policy and practise which arise in their work.

THE PUBLIC AND ITS UTILITIES.

By William G. Raymond. N. Y., John Wiley & Sons, 1925. 346 pp., charts, tables, 9 x 6 in., cloth. $3.50.

This is an elementary discussion of the fundamental problems involved in the relations between the public and its utilities. The author endeavors to set forth the respective rights and mutual obligations of utilities and the public, with particular attention to the principles that should govern the establishment of prices, the nature and bases of proper public control and regulation, the fixing of a fair rate of return and the determination of the fair value of the utility. The book is intended primarily for legislators, municipal officers and members of the general public rather than for engineers.

PLATINUM METALS.

By Ernest A. Smith. Lond. & N. Y., Isaac Pitman & Sons, (1925). (Pitman's Common Commodities and Industries). 123 pp., illus., 7 x 5 in., cloth. $1.00.

Describes the occurrence and distribution of these metals, the sources of supply, methods of mining and refining, and their physical and chemical properties. Gives an account of their industrial uses in some detail and treats briefly of the industry and of prices. The book is not intended for expert metallurgists but for those with a general or a commercial interest in these metals.

THE BUTTON INDUSTRY.

By W. Unite Jones. Lond. & N. Y., Isaac Pitman & Sons [1924], illus., (Pitman's Common Commodities and Industries). 7 x 5 in., cloth. $1.00.

A history of the industry, particularly as developed in England. Contains a little information about methods of manufacture but is chiefly concerned with economic phases. It is, the author says, the first history of the trade.

HISTORY OF BLEACHING.

By S. H. Higgins. Lond. and N. Y., Longmans, Green & Co., 1924. 176 pp., illus., 9 x 6 in., cloth. $3.50.

More properly a history of the British bleaching industry. Traces its developments from the earliest times down to the present in readable fashion, without too much detail. A first attempt to record the history of an important trade.

ORGANIC SYNTHESES, v. 4.

By Oliver Kamm, editor-in-chief. N. Y., John Wiley & Sons, 1925. 89 pp., 9 x 6 in., cloth. $1.50.

Concerned with twenty-eight organic substances sometimes needed in research work, which are not usually available in commerce and therefore must be made by the chemist. Full directions for their preparation on a semi-commercial scale are given.

LIGHTING FIXTURES AND LIGHTING EFFECTS.

By M. Luckiesh. N. Y., McGraw-Hill Book Co., 1925. 330 pp., illus., 9 x 6 in., cloth. $4.00.

Mr. Luckiesh discusses lighting from an esthetic, rather than a commercial or industrial point of view. The effects of color and of painting, the design of fixtures, methods of lighting and the decorative uses of light are given attention. Throughout the book, the author shows how scientific control of light may be secured without loss of decorative quality.

DIE KONDENSATION BEI DAMPFKRAFTMASCHINEN.

By K. Hoefer. Berlin, Julius Springer, 1925. 442 pp., illus., diagrs., tables, 9 x 6 in., boards. 22,50 gm.

This book owes its origin, according to the author, to the lack of any work giving a comprehensive account of the many novelties in condenser practise which have found a place in steam power plants during the past fifteen years. It is intended for use as a textbook and also as a reference book for use in practical work. The author has tried to present a succinct account of all phases of condenser practise, which will be as complete as possible and thoroughly modern in outlook. Attention is given to marine engine practise as well as to plants on land.

HYDROMECHANIK.

By M. Samter. Charlottenburg, Robert Kiepert, 1925. 96 pp., 9 x 6 in., paper., 3,20 mk.

Object is to make the student conversant with the most important laws of hydrostatics and hydrodynamics, without too great an expenditure of time. To accomplish this, the author has abbreviated the necessary theoretical demonstrations to the briefest possible forms and has used the space thus saved for complete solutions of many examples which are important in practise and which are intended to give the young engineer the necessary accuracy and experience in calculation.

HILFSBUCH FUR DIE ELEKTROTECHNIK—STARKSTROMAUSGABE.

By Karl Strecker. 10th edition. Berlin, Julius Springer, 1925. 739 pp., illus., diagrs., 8 x 5 in., cloth. 13,50 gm.

Strecker's "Hilfsbuch" is now issued in two volumes, of which the present one is devoted to heavy-current engineering. The book gives first the usual mathematical and physical data and tables and a brief review of the theory of electricity and magnetism. This is followed by information on measurements and measuring apparatus. Succeeding chapters treat of electromagnets, transformers, dynamos, storage batteries, generating stations, transmission and distribution, power utilization, lighting, heating, electrochemistry and safety devices. The book is a useful desk book for ready reference. Numerous lists of references to the literature are included. The text is the work of a number of specialists.

GASMASCHINEN UND OLMASCHINEN, v. 2.

By Alfred Kirschke. Ed. 2. Ber. u. Lpz., Walter de Gruyter & Co., 1925. 144 pp., illus., diagrs., 6 x 4 in., cloth. 1,25 rm.

This volume treats briefly of the important structural details of large gas engines, oil engines, and oil and gas turbines. The first chapter discusses the generation and use of gas fuel, and the method of working and construction of large gas engines. The second and largest chapter treats of four and two cycle oil engines and the construction of engines for various purposes. Much of the space is given to Diesel engines. The final chapter describes the various types of gas and oil turbines.

FACTORY LAY-OUT, PLANNING AND PROGRESS.

By W. J. Hiscox. Lond. & N. Y., Isaac Pitman & Sons, 1924. 184 pp., charts, 9 x 6 in., cloth. $2.25.

The author, who has for many years been brought into daily contact with the problems that arise out of modern industrial conditions, here presents his views on the ethics of factory planning. A scheme of factory organizations, prepared with especial reference to British conditions, is presented.

DESIGN OF CRANES AND HOISTS.

By Hermann Wilda. 2nd revision English edition. Lond., Scott, Greenwood & Son, 1925. (Broadway Engineering Handbooks, v. 6). 159 pp., diagrs., 8 x 5 in., cloth. $2,50. (Gift of D. Van Nostrand Co., N. Y.).

A concise reference book for the designer, giving practical information on the design of the elements of lifting tackle of various types, the formulas for calculating their dimensions and the customary constants.

CONNECTING AND TESTING DIRECT-CURRENT MACHINES.

By F. A. Annett and A. C. Roe. N. Y., McGraw-Hill Book Co., 1925. 237 pp., illus., diagrs., tables, 9 x 6 in., cloth. $2.50.

Based on material which has appeared in "Power" during recent years, this book is intended to assist electricians in solving winding problems, and students in industrial schools in understanding practical problems connected with the repair and operation of electrical machinery.

The book in divided into two parts. The first deals with reconnecting machines for a change in voltage or speed, or both. Part two treats of the location and removal of faults in machines. In both parts the authors not only discuss the questions practically; they also explain the principles involved and the reasons for the suggested methods.

COMPOSITION OF TECHNICAL PAPERS.

By Homer Andrew Watt and Philip B. McDonald. 2nd edition. N. Y., McGraw-Hill Book Co., 1925. 429 pp., 8 x 5 in., cloth. $2.00.

A clear, direct statement of the principles of expository writing, accompanied by a selection of writings by engineers

which illustrate the various types. Intended to teach engineering students to write better technical papers.

The new edition has been carefully revised and new matter has been added.

CHEMIKER-KALENDER, 1925.

By Rudolph Biedermann. Revised by Walther Roth. Berlin, Julius Springer, 1925. 2 v., ilus., diagrs., tables, 6 x 4 in., cloth. $3.00.
(Gift of B. Westermann Co., N. Y., Agents).

The forty-sixth annual issue of this well-known handbook retains the arrangement of earlier editions. New materials has been added in many places, however, and the numerical data have been carefully revised, so that the book is thoroughly up to date. The work makes available, at a very moderate price, an amazingly large collection of the physical and chemical data, processes, etc., most frequently wanted by chemists, metallurgists and physicists.

CADMIUM; Its metallurgy, Properties and Uses.

By Norman F. Budgeon. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1924. 239 pp., ilus., diagrs., tables, 9 x 6 in., cloth. 21 s.

A comprehensive digest of all available information relative to cadmium, collected from widely scattered sources. The occurrence, properties, extraction and uses of this metal are considered in detail and full references to the sources of information are given. This is the first book devoted solely to this metal and should be of interest to chemists, metallurgists, and manufacturers of alloys.

DER BAU DER STARRLUFTSCHIFFE.

By Johannes Schwengler. Berlin, Julius Springer, 1925. 99 pp., diagrs., 10 x 7 in., paper. 4,80 m.

A general discussion of the structural and theoretical problems involved in the design and construction of rigid airships. Written from the point of view of the structural engineer, and without any treatment of the propelling machinery. The book is apparently the pioneer work on its subject.

AUTOMOBILE ENGINES.

By Arthur W. Judge. Lond., Chapman & Hall, 1925. (Motor Manuals, v. 1.) 189 pp., illus., diagrs., 8 x 5 in., cloth. 4 s.

The first of a series of manuals which will present the elementary aspects of automobiles in a simple, non-technical manner. Intended especially for owners and users who wish sound information on the theoretical and practical sides of the subject. This volume is confined to the engine. It includes the theoretical principles involved, an account of the different types in use and of their components, and sections on such supplementary topics as testing, lubrication, cooling and maintenance.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the acccuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—E. T. Benderoth, 834 Golden Ave., Baryman Apt., Los Angeles, Calif.
2.—Clyde E. Bentley, 2815 Kelsey St., Berkeley, Calif.
3.—Edward F. Bradley, c/o So. Calif. Edison Co., Camp 62, Big Creek, Calif.
4.—W. T. Chappell, 3708 5th Ave., Pittsburgh, Pa.
5.—G. de La Rochette, c/o Westinghouse Elec. Int'l. Co., 2 Norfolk Strand, London W. C. 2, England.
6.—Harry N. Gilbert, 379 Cottage Ave., Glen Ellyn, Ill.
7.—William J. Gough, Box 230, Sea Cliff, L. I., N. Y.
8.—Harry A. Gould, So. Calif. Edison Co., 1201 W. 2nd St., Engg. Dept., Los Angeles, Calif.
9.—Thomas L. Henritze, P. O. Box 27, Pikeville, Ky.
10.—William B. Hoey, High Tension Supplies Co., Wilmington, Del.
11.—F. M. Kenney, 611 North Lime St., Lancaster, Pa.
12.—I. J. Larson, 71 Roseville Ave., Newark, N. J.
13.—W. L. McGeehan, c/o The Ohio Power Co., Philo, Ohio.
14.—H. J. Mitchell, 42 Second St., Elmhurst, L. I., N. Y.
15.—Austin W. Moore, 63 W. Parker St., Scranton, Pa.
16.—Wm. Shiel Norton, 10 Grove St., New York, N. Y.
17.—David M. Oseroff, 505 12th St., Brooklyn, N. Y.
18.—A. Shohan, Lombard, Ill.
19.—Gilbert H. Strand, Western States Gas & Electric Co., Camp R, Placerville, Calif.
20.—I. B. Watkins, 124 East Symmes St., Norman, Okla.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Underground Transmission Circuits Today, by D. C. Ober, Cleveland Electric Illuminating Co. Illustrated by slides. April 3. Attendance 45.

Boston

The Merchant Marine, by A. E. Waller, Ward-Leonard Co. March 20. Attendance 60.

A Symposium on the Origin of Life, by Dr. Harlow Shapley, astronomer, Dr. G. H. Parker. Biologist and Dr. Kirsopp Lake, theologian. Illustrated with slides. Talks were also given by Messrs. Farley Osgood, National President, A. I. E. E. and H. B. Smith, Vice-President, District No. 1. A dinner preceded the meeting. March 28. Attendance 350.

In the Lands of Mohammed, by H. B. Smith, Worcester Polytechnic Institute. Illustrated with slides. April 10. Attendance 30.

Cincinnati

The Failure of Solid Insulation, by Wm. A. Del Mar, Habirshaw Electric Cable Co. March 12. Attendance 47.

Cleveland

Some Illuminators I have Met, by Ward Harrison, National Lamp Works of General Electric Co. Joint meeting with Illuminating Engineering Society, after which a trip was made to the School of Lighting, the Lighting Research Laboratories and the Street-Lighting Exhibit. March 19. Attendance 162.

Connecticut

Control for Industrial Motors, by F. R. Fishback, Electric Controller and Manufacturing Co. Illustrated with slides. March 20. Attendance 40.

Denver

The Scope and Plan of Organization and *Some Problems and Equipment of the General Iron Works Co.*, by R. W. Gordon and H. B. Barnes, General Iron Works Co. After the talks an inspection trip was made to the Company's plant at Englewood. March 21. Attendance 50.

Detroit-Ann Arbor

Getting the Most from Light, by Professor H. H. Higbie, University of Michigan. Illustrated with slides and pieces of lighting equipment. March 17. Attendance 50.

Erie

Inventions and Patents, by A. A. Buck, General Electric Co. March 17. Attendance 85.

Fort Wayne

Super-Power Scheme, by L. B. Andrus, Central Indiana Power Co. The speaker told of linking the industrial districts of Pittsburgh, Toledo, Chicago, Northern and Central Indiana, West Virginia, Virginia and North and South Carolina in an electrical power loop, and

Business Phases of Electricity in Industry, by R. M. Feustel, Indiana Service Corp. and

Application of Electricity in Industry, by Chester I. Hall, General Electric Co. March 19. Attendance 150.

Indianapolis-Lafayette

Radio Interference, by Professor A. M. Wilson, University of Cincinnati. March 27. Attendance 100.

Kansas City

Informal Get-Together Meeting. The following officers were elected; Chairman, W. E. A. Nottorf; Secretary-Treasurer Henry Nixon. Dinner preceded the meeting. March 19. Attendance 16.

Lehigh Valley

New Fields for Radio Signaling, by E. F. W. Alexanderson, Radio Corporation of America. The speaker told of the great commercial use his company was making of radio telephony. Illustrated. Joint meeting with Lafayette Branch, A. I. E. E., and Lehigh University Radio Club. March 13. Attendance 155.

Los Angeles

Supervisory Control for Remote Operation of Electrical Sub-Stations, by B. H. Hatch, General Electric Co. and P. B. Garrett, Westinghouse Electric & Mfg. Co. Illustrated by slides, motion pictures and demonstration equipment. March 10. Attendance 157.

Madison

An Analysis of Short-Wave vs. Long-Wave Radio Systems, by Professor Edward Bennett, University of Wisconsin and

Effect of Static on Radio Receiving Systems, by L. J. Peters, University of Wisconsin. April 2. Attendance 35.

Milwaukee

The Institute and the Engineering Professor, by Farley Osgood, National President, A. I. E. E. Secretary F. L. Hutchinson spoke on Institute affairs. The meeting was preceded by a dinner. March 18. Attendance 100.

Discussion on the *service-at-cost* contract between the City of Milwaukee and the Milwaukee Electric Railway & Light Co. A resolution was made that the Engineers' Society of Milwaukee express its opposition to this contract. March 18. Attendance 100.

Minnesota

Dinner-Dance. February 16. Attendance 106.

New York

A meeting of the New York Section was held on the evening of Tuesday, April 21, 1925, in the auditorium of the Public Service Building, Newark, N. J. The first Section meeting to be held outside of New York. The innovation proved a great success. Chairman Barnes called upon President Osgood of the Institute, who made a short address welcoming the New York Section to Newark. The speaker of the evening, Mr. Clement E. Chase, principal assistant engineer of the Delaware River Bridge Commission, gave an interesting and well illustrated talk on "Electrical Features of the Delaware River Bridge," covering not only the electrical features, but problems of design and construction with which this Commission as been confronted. Preceding Mr. Chase's talk, Chairman Barnes called upon Secretary Tapscott to read the report of the Tellers Committee on election of Section officers or 1925-26. The following officers were announced for the coming year: Chairman H. A. Kidder, Secretary-Treasurer H. V. Bozell, Members of the Executive Committee, W. A. Del Mar and G. H. Stickney, Junior Past Chairman H. H. Barnes. Chairman elect Kidder then gave a short address.

During the afternoon preceding the meeting, members of the Section were taken, as guests by the Public Service Electric Company, on an Inspection Trip through the new Kearney Power Station. On the return from this trip a Get-Together Dinner was served at the Robert-Treat Hotel. The attendance at the meeting was about one hundred and seventy, over one hundred of whom had made the inspection trip.

Niagara Frontier

Lightning, by F. W. Peek, Jr., General Electric Co. March 26. Attendance 70.

Pittsburgh

Two Points of View, by C. F. Kettering, General Motors Research Corp. The speaker spoke on psychology, particularly applied to those engaged in engineering and research work. March 10. Attendance 300.

Pittsfield

Foundation Stones of Electrical Discovery and Milestones of Electrical Progress, by T. D. Lockwood. March 16. Attendance 125.

The Relation of the Engineer to Society in General, by Farley Osgood, National President, A. I. E. E., and

My Experiences in Seven Wars, by Captain Irving O'Hay. A short talk was also given by Professor H. B. Smith, Worcester Polytechnic Institute. April 7. Attendance 239.

Portland

Excursion to the Annual Educational Exposition at the State College. Joint with N. E. L. A. A feature of the engineering section of the show was the high-tension insulator test carried on by a group of students under the super vision of Professor F. O. McMillan. February 21. Attendance 57.

The Skagit Municipal Power Plant, by Carl F. Uhden, Chief Engineer, City of Seattle. Illustrated by slides. Refreshments were served. March 11. Attendance 100.

Rochester

The Klydonograph, by Dr. Joseph Slepian, Westinghouse Electric & Mfg. Co. Slides illustrating some of the results were shown. March 6. Attendance 55.

San Francisco

Remote Metering and Control, by R. D. Evans, Westinghouse Elec. & Mfg. Co. Illustrated by slides, and

Visual Type of Supervisory Control, by P. B. Garrett, Westinghouse Electric & Mfg. Co. Demonstration. February 27. Attendance 120.

Where the Cost of Electricity Occurs, by Lester S. Ready, California Railroad Commission. Illustrated by slides. March 27. Attendance 110.

Schenectady

Automatic Stations and Their Remote Supervision, by C. Lichtenberg, General Electric Co. Illustrated by slides and moving pictures. The speaker also discussed the newly developed supervisory systems for the control and indications of remote apparatus by the use of telephone wires and telegraphing instruments. February 27. Attendance 300.

The Application of Engineering Principles to Advertising, by T. J. McManis, General Electric Co. The speaker showed how market determinations are made, how buying habits are determined, how appeals are prepared, and channels found for them, and cited specific cases of effects and results of advertising on sales volume. March 13. Attendance 250.

A New Separately Excited Synchronous Motor, by Val A. Fynn, Consulting Engineer. Illustrated by slides. March 27. Attendance 200.

Seattle

The Kirsten Propeller, by Professor F. T. Kirsten, University of Washington. By means of working models the speaker showed the device in operation. Slides and motion pictures were also shown. February 18. Attendance 178.

Spokane

Electricity's Contribution to Civilization, by H. V. Carpenter, State College of Washington, and

Recent Power Developments, by J. B. Fisken, Washington Water Power Co. Joint meeting with A. S. M. E. March 27. Attendance 41.

Southern Virginia

South America, by Calvin W. Rice, National Secretary, A. S. M. E. The speaker also made some remarks concerning the International Engineering Congress held at Rio de Janeiro in 1922. Joint meeting with A. S. M. E., A. S. C. E. and A. A. E. March 19. Attendance 36.

Springfield

Lightning, by F. W. Peek, Jr., General Electric Co. Illustrated by motion pictures, and

Some Interesting Phases of Engineering in India, by R. A. Packard, Ludlow Manufacturing Associates. Illustrated with slides. March 24. Attendance 115.

Toledo

Electrical Meters, by F. H. Bowman, General Electric Co. Illustrated by meters, instruments and slides. March 18. Attendance 27.

Toronto

Sudden Short-Circuit Phenomena in A-C. Systems; A. H. Frampton, University of Toronto, and

Relay Protection of Short Parallel Feeders, by Mr. Griffith. March 13. Attendance 36.

Trend in Substation Design, by W. F. Sutherland, Toronto Hydro-Electric System. Illustrated by slides and drawings. March 27. Attendance 73.

Utah

Radio, by Colonel J. F. Dillon. Interference was the main topic of discussion. March 12. Attendance 57.

Vancouver

Steam Storage and Accumulators, by A. J. T. Taylor, Vickers & Combustion Engineering Corp., Illustrated by slides. March 13. Attendance 80.

Alouette Power Developments, by E. E. Carpenter, British Columbia Electric Railway Co. Illustrated by slides. April 3. Attendance 60.

Washington, D. C.

The United States—Alaskan Cable, by Col. C. J. Sloane, U. S. Signal Corps. The paper related to the cost, installation and operation of this cable connecting the Northwestern U. S. with Alaska, which was installed and is operated by the Signal Corps of the U. S. Army. Refreshments were served. March 10. Attendance 68.

Worcester

In the Land of Mohammed, by Professor H. B. Smith, Worcester Polytechnic Institute. Ladies Night. Refreshments were served. March 12. Attendance 90.

BRANCH MEETINGS

Alabama Polytechnic Institute

Induction Motors, by R. J. Cooper. Illustrated by slides. March 25. Attendance 25.

Storage Batteries, by N. E. Grubbs, student. April 1. Attendance 25.

Business Meeting. April 8. Attendance 12.

University of Arizona

The New Southern Pacific Locomotive, by B. L. Jones,

My Work Since I Left School, by Edward Moyle. A moving picture was shown. March 3. Attendance 12.

Action of the Telephone Sub-Set, by C. L. Carnes. A moving picture was shown. March 19. Attendance 15.

Brooklyn Polytechnic Institute

High-Power Transmission, by A. B. Dibner, and

Illumination, by S. Tarkas. March 14. Attendance 29.

Carnegie Institute of Technology

The Method of Transmitting Pictures by Telephone, by M. B. Long, Western Electric Co. Illustrated by slides. A motion picture, entitled "The Manufacture of Insulated Wires and Cables," was shown. April 1. Attendance 65.

Case School of Applied Science

The Use of Controllers and Control Equipment, by V. P. Fishback, Electric Controller and Manufacturing Co. Illustrated. February 20. Attendance 52.

Telephone Transmission, by F. E. Jones, Ohio Bell Telephone Co. March 13. Attendance 32.

Clarkson College of Technology

Motor Control, by V. P. Fishback, Electric Controller and Manufacturing Co. March 27. Attendance 46.

Evolution of Transformers, by Professor Powers. Illustrated by slides, and

Early Development of Hydraulic Plants and Distribution, by Chas. Pohl. April 7. Attendance 15.

University of Colorado

Auto-Valve Lightning Arresters, by Frank Pexton. Two sets of slides entitled respectively "Static Condensers for Power Factor Correction" and "Electrical Porcelains" were shown. The papers accompanying the slides were read by Mr. Cartwright. March 11. Attendance 40.

University of Denver

Recent Developments on the Curtis Steam Turbine, by A. L. Jones, General Electric Co. Refreshments were served. March 12. Attendance 25.

High-Temperature Insulation, by C. G. Diller. Illustrated. March 20. Attendance 35.

Inspection trip through the General Electric Company's radio Broadcasting station KOA. March 27. Attendance 36.

University of Florida

Early Development of Steam Turbine. Illustrated by slides. March 27. Attendance 12.

University of Idaho

Opportunities for the Graduate Engineer in the Telephone field, by Messrs. Hueffner, Jones, Shaw and McCarthy, Bell Telephone System. March 18. Attendance 36.

Kansas State College

Transmission of Photographs by Wire, by M. B. Long, Western Electric Co. Illustrated by slides. March 5. Attendance 87.

Remote Metering, by L. E. Northshield, General Electric Co. Illustrated by slides. March 19. Attendance 101.

University of Kansas

Business Meeting. February 26. Attendance 39.

Self Analysis as a Research Problem, by M. M. Boring, General Electric Co., and

Engineering Sales Work, by C. A. Degering, General Electric Co. A moving picture, entitled "The Story of Okonite," was shown. Entertainment. March 5. Attendance 72.

Motion picture, entitled "Westinghouse—the Institution," was shown. Refreshments were served. March 19. Attendance 67.

Annual Banquet. Talks by J. A. Parkinson, F. Ellis Johnson, H. E. McDonald, J. P. May, C. A. Poppino, L. E. Allen, E. H. Lindley and G. C. Shaad. March 26. Attendance 170.

Lafayette College

Problems of Illumination, by Professor King. February 21. Attendance 19.

Methods of Illumination, by Professor King. March 21. Attendance 11.

Marquette University

Humorous papers were given by Messrs. M. Smith and H. Armfield. Several essays were read by Professor Kartak. A short talk was also given by Dean French. March 17. Attendance 42.

Massachusetts Institute of Technology

What the College Graduate Goes Up Against and How to Meet It, by Farley Osgood, National President, A. I. E. E. March 27. Attendance 95.

University of Michigan

Power Development at Niagara Falls, by Morris H. Lloyd. March 12. Attendance 30.

The Transmission of Pictures by Wire, by R. D. Parker, American Telephone & Telegraph Co. Illustrated by slides. March 20. Attendance 200.

A moving picture, entitled "The Process of Making Insulation and Applying It to Wires and Cables," was shown. April 2. Attendance 70.

School of Engineering of Milwaukee

Training for College Graduates, by H. S. Day, Wisconsin State Telephone Co. March 13. Attendance 34.

University of Minnesota

Corona Losses in High-Tension Transmission Lines, by Professor W. T. Ryan,

Measurement of High-Frequency Current, by Professor C. M. Jansky, Jr., and

Demonstration of High-Frequency Current and of Corona, by Mr. Schnell. March 11. Attendance 75.

Missouri School of Mines and Metallurgy

Electric Distribution Relative to Customer Service, by L. O. Williams, Jr. March 20. Attendance 17.

University of Nebraska

High-Tension Transmission Lines in Eastern Nebraska and Western Iowa, by Mr. Gunther, Continental Gas and Electric Co. March 21. Attendance 50.

University of Nevada

A talk upon the organization of the San Francisco Division of the Bell Telephone Company was given by R. J. Jeffner' Director of Educational Relations. His talk was supplemented with talks by Messrs. Roberts, Home, and Parsons on the work in the various departments. February 27. Attendance 104.

Railroad Electrification, by A. H. Babcock, Southern Pacific Co. March 18. Attendance 36.

University of North Carolina

A Desirable Intensity of Illumination, by B. C. Cooper, and

Lamp Efficiencies and Applications, by P. M. Rutherford. March 12. Attendance 12.

The Heritage of the Electrical Engineer, by Professor J. E. Lear, and

The Interdependence of Electrical and Mechanical Engineering, by Professor E. G. Hoefer. March 26. Attendance 23.

Business Meeting. March 30.

University of North Dakota

The Three-Element Oscillograph, by Donald Donaldson and Edson Conger, students. March 23. Attendance 21.

University of Notre Dame

Peculiar Performance of Direct-Current Motors, by E. Pfister, student, and

Engineering as a Profession, by Daniel J. O'Neil, student. February 4. Attendance 3 .

Deisel-Engine Installations in Medium-Size Power Plants, by H. J. Harstick, student, and

Phenomena of Lightning and Thunder, by M. Knauss, student. Refreshments were served. February 16. Attendance 24.

The Application of Electricity in Oil Production, by A. Daly, student, and

Railway Signaling Systems, by R. R. Trevino. March 2. Attendance 23.

Ohio Northern University

Oil Insulation of Transformers, by Mr. Thompson. March 12. Attendance 22.

Business Meeting. Short talk was given by Professor Beyer. March 26. Attendance 18.

The Single-Phase Motor, by Mr. Ring. Short talks were given by Professors Webb, Campbell, Beyer and Dean Elbin. The following officers were elected: Chairman, Mr. Seslar; Vice-Chairman, Mr. Grace; Secretary, Mr. Boulton, and Treasurer, Mr. Lee. April 9. Attendance 40.

Oklahoma Agricultural and Mechanical College

Automatic Telephone Operation, by Francis Todd, student, and
Rural Electrification Problems, by Roy Hayman, student. February 19. Attendance 19.

Oregon Agricultural College

Business Meeting. April 17. Attendance 21.

Purdue University

Fractional-Horse power Motors, by E. B. George, General Electric Co. Illustrated by motion picture. March 17. Attendance 76.
Supervisory Control, by L. Dorfman, Westinghouse Electric & Mfg. Co. March 31. Attendance 40.

Rensselaer Polytechnic Institute

Aluminum and Its Alloys, by Dr. Zay Jeffries, Aluminum Company of America. Joint meeting with Rensselaer Branches of other engineering societies. March 31. Attendance 340.

Rhode Island State College

The Economy of Power-Factor Correction, by L. G. Burlingame, and
Current Reviews, by H. Hopkins. January 22. Attendance 18.
First-aid lecture and demonstration, by Dr. W. R. Redden. February 16. Attendance 77.
A motion picture, entitled "Okonite," was shown. February 18. Attendance 18.
The Electrification of the St. Paul, Milwaukee and Chicago Railroad, by C. L. Gledhill, and
The New Haven Railroad, by M. Gluckman. March 4. Attendance 16.

Rutgers University

Electrification of Railways, by H. Cromley, student. A motion picture, entitled "The Benefactor," was shown. March 16. Attendance 24.

South Dakota School of Mines

Searchlights, by Professor E. E. Clark. Illustrated. March 18. Attendance 15.

University of South Dakota

Brief Synopsis of Tests Carried on at General Electric Company, by Mr. Lawton. February 26. Attendance 7.

Syracuse University

A number of interesting topics were discussed. February 17. Attendance 23.
Super Power, by Mr. Reed. March 3. Attendance 21.
Motion picture was shown. March 10. Attendance 22.
Power-Factor Correction, by Mr. Goodwin. March 17. Attendance 22.
The Power Stations of the New York Central Railroad Company, by Mr. Olmstead. March 24. Attendance 23.
The Power Plant at Amsterdam, New York, by Mr. Puls. March 31. Attendance 22.

Agricultural and Mechanical College of Texas

Construction of a 65,000-kv-a. Alternator, by E. F. Brendt.
The Problem of Obsolete Machinery, by E. I. Bailey, and
Power-Factor Correction, by G. C. Buchanon. March 13. Attendance 55.

University of Texas

A film covering the development of hydroelectric power in the United States was shown. March 4. Attendance 18.
A film dealing with the various methods of insulating with rubber was shown. March 31. Attendance 24.

University of Utah

Radio Interference, by K. V. Laird, Capitol Electric Co. March 24. Attendance 7.

Virginia Military Institute

The Development of the Incandescent Lamp, by E. T. Morris.
The Developments in A-C. Apparatus during 1924, by J. C. Owen. March 23. Attendance 46.

University of Virginia

Lightning, by T. M. Linvolle, student,
Why Are You an Engineer?, by J. M. Roberts, student, and
The Failure of the C. M. and St. Paul Railroad, by W. A. Whitaker, student. April 17. Attendance 13.

Washington University

The Transmission of Pictures by Wire, by M. B. Long, Western Electric Co. Illustrated with slides, showing the actual apparatus used and some of the results obtained. March 6. Attendance 75.
A film, entitled "The Single Ridge," was shown. The film showed the entire process of making insulation for electric wires. March 12. Attendance 35.

University of Washington

The Diversified Uses of Electrical Energy in the Modern Saw Mill, by Robert E. Gray, Snoqualmie Falls Lumber Co. March 3. Attendance 22.

West Virginia University

The Maintenance of Bearing and Housing Fits, by Mr. Berry,
Station KFKX, by Mr. Naylor,
Current Transformers, by Mr. Robinson, and
Sixteen Years of Electric Locomotive Service, by Mr. Mountain. March 27. Attendance 25.
Oil-Insulation for Oil Circuit-Breakers, by Mr. Beardslee,
Engineer R. O. T. C. Camp, by Mr. Neill, and
Uniform Lighting System in the City of Lansing, Michigan, by Mr. Addis. April 3. Attendance 24.

Yale University

Physiology in Industry, by Professor Yandell Henderson. March 18. Attendance 90.
Books and Life, by Professor J. R. Crawford. March 25. Attendance 60.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, experienced in developing small electrical machines and devices. Knowledge of spot welding and heat resistance units desirable. In reply cite some problem solved that was extraordinary stating how it was accomplished. Also cover general experience, age, education, and starting salary expected. Location, Middlewest. R-5962.

METERMEN, (2), familiar with single and polyphase meter testing and with type 7 demand meters, also familiar with central station meters and their testing and calibrating. Apply by letter with references. Location, Middlewest. R-6140.

NEW BUSINESS MAN, for company operating public utility properties in Kentucky and Tennessee. Must have had experience in obtaining new business in small cities and towns. Replies wanted only from men who can get results. State age, salary wanted and experience with references. Traveling. Location, South. R-6155.

ELECTRICAL OR MECHANICAL ENGINEER, with practical experience in the manufacture of Incandescent Lamps. Apply by letter stating age, education, experience and when available. Location, Middlewest. R-6227.

MEN AVAILABLE

ENGINEERING EXECUTIVE, 40, single, world-wide experience electrical, civil mechanical construction, operation. Traction, hydroelectric, power houses, steam and Diesel, electro-chemistry, water supply, communication. Made financial, technical investigations twenty-nine countries. War service, five and one-half years, British Army, France, Royal Engineers, Flying Corps, General Staff, lieutenant colonel. Fluent French, working knowledge German, Spanish. B-9175.

TECHNICAL GRADUATE, age 27, seven years' practical experience on electrical construction and maintenance. Permanent connection with a growing, reliable concern desired. Associate Western Society of Engineers. Location preferred, Middlewest or East. Available immediately. B-8761.

GRADUATE ENGINEER, B. S. in E. E. '25 desires a position with a future where he can gain experience and at the same time make a fair salary. Either public utility or private enterprise. Expect to work hard and really study whatever phase of engineering I enter. Location preferred, South. Available middle of June. B-9615.

ELECTRICAL ENGINEER, technical graduate, married, 29, G. E. test; one year standardizing meters, instruments, gages, three years design, drafting of power houses, high and low tension substations, switch and transformer structures, one year assistant on generating stations and substations, high tension telephone systems. Desires position with construction company, industrial concern, public utility. Available on reasonable notice. B-9614.

ELECTRICAL AND VALUATION ENGINEER, formerly with the N. Y. State Public Service Commission. Specialist on mining, industrial and public utilities problems, investigations, property records, inventories and appraisals. Familiar with the working conditions in Mexico and South America. B-9636.

ELECTRICAL ENGINEER, B. E. E., desires position with public utility or consulting engineer, where executive and organizing, as well as engineering ability is required. Four years' experience with and at present employed by large Eastern public utility. Location, immaterial. B-9639.

ELECTRICAL ENGINEER, 31, married, ten years' broad experience; five years as electrician, one year telephone engineering, one year sales engineering, two years superintendent of construction of transmission lines and outdoor substations, one and one-half years' Westinghouse service. Available two weeks' notice. Location, anywhere. B-9657.

CONSTRUCTION SUPERINTENDENT, age 40, twenty years' experience; ten years' experience in Latin America as superintendent of electrical construction including power plant, tramway, distribution and high tension lines. Nationality Canadian, speak English and Spanish. Ten years with present employers. Available upon reasonable notice. B-9642.

ENGINEER, 32, single, college graudate, La Salle Industrial Management Course, employed. Designer of industrial and power plants, tools; ten years' experience, best qualified for efficiency, analysis and research, cost and waste elimination, management. Knows foreign market well. Linquist. Available April 26th. B-7478.

GRADUATE ELECTRICAL ENGINEER, 28, American, married, five years drafting and design for power house, substation and transmission line construction with material requisition experience. Desires position, preferably New York City, but will go anywhere in U. S. B-4217.

GRADUATE ELECTRICAL ENGINEER, Dipl. Ing., 28, single, several years' experience in research laboratory, electrification of railroads, construction and maintenance of power and substations, good mathematician and thoroughly familiar with A-C. problems. Desires responsible position with large concern or utility company. Speaks English, German, French and Spanish. Available on fourteen days' notice. B-9671.

GRADUATE ELECTRICAL ENGINEER, 32, desires position with public utility or construction company. Ten years' general engineering experience. Familiar with the design and installation of high voltage apparatus. Location desired, Western Pennsylvania or the East. B-9675.

GRADUATE ELECTRICAL ENGINEER, four and one-half years' experience in construction and maintenance of an electrical railway, also one year operating and power house installation experience. Desires a position with a company offering opportunities for advancement. Available on reasonable notice. Location immaterial. B-9660.

ELECTRICAL ENGINEER, 30, single, M. I. T. 1918; G. E. Test, design, construction and engineering experience with large power company. Design experience with large engineering company; appraisal experience. Interested in power plant engineering, management, engineering sales or manufacturing. Location, New England preferred, but any considered. B-5226.

RECENT GRADUATE desires start in engineering. Available after May. Location, East or Middlewest. B-9686.

TECHNICAL GRADUATE, E. E., 1921, 25, married; six months General Electric test, one and one-half years' experience in construction of substations, transmission lines, distribution systems, etc., in large public utility, two years large steel company, installing substations, rolling mill drives, studying rates, etc. Desires similar position with large growing organization, or sales company. Best references, available two weeks. B-8047.

ELECTRICIAN, age 35, technical education, broad experience with central and substation work, thoroughly familiar with handling the erection, operation and maintenance of raw sugar machinery. Now employed, but would like a place on a system where considerable changes, additions, etc., are taking place. Location immaterial. Minimum salary $3600 per year. Available on reasonable notice. B-9687.

GRADUATE ELECTRICAL ENGINEER with unlimited chief engineer's marine license, testing experience with General Electric Company, and some experience in system operating department of large public utility. Desires position of responsibility and chance for advancement, where conscientious application will be appreciated. Excellent references. Available immediately. B-7947.

TECHNICAL GRADUATE, with experience in electrical work desires a position as sales engineer with some reputable electrical manufacturing company. Will consider a straight commission proposition. B-6726.

ELECTRICAL ENGINEER, experienced in the design, construction and operation of electric power plants and electric apparatus, desires position as manager of an electric light and power company, of which we can purchase an interest if conditions warrant. B-9701.

ELECTRICAL ENGINEER, age 37, married. Familiar with operation and maintenance steam electric stations and boiler-houses. Six years' installation work and later district engineer large electrical manufacturer. Wide experience industrial applications. Steam economy work large paper manufacturer. Graduate mechanical engineer. Desires connection power company, engineering firm. B-6764.

POWER HOUSE-SUBSTATION ENGINEER, age 38, technical graduate, capable of assuming full engineering responsibility. Now employed in capacity as above. Available June 1st. Ten years' broad experience; salary according to responsibility and position. B-2123.

TECHNICAL GRADUATE of electrical engineering from a superior ranking technical institution. Electrical experience in the round house of electrified railroad. Student majored in power transmission and distribution. Age 25, single. Prefers employment with public utility company. Available after July 1, 1925. B-9709.

ELECTRICAL ENGINEERING INSTRUCTOR in middle western state university, desires an assistant professorship. Reason for change is opportunity for more rapid advancement. Eight years' teaching experience, the last four of which have been in the handling of basic courses in electrical engineering. Four summers of engineering experience. Age 34, married. B-9710.

COMMERCIAL ENGINEER, E. E., at Lehigh, age 35, married, desires connection with progressive firm in commerical capacity or engineering sales work. Experience; Westinghouse apprenticeship, turbine erection and operation, applying steam and electricity to various industries, evaluations, sale of power plant equipment, analysis material handling and sale of electric trucks. In last mentioned now, but business conditions cause results too intermittent. B-9703.

GRADUATE ENGINEER, five years' experience in the estimating construction and maintenance of transmission and distribution systems of a public utility, desires a position with a company offering opportunities for advancement. Present position, assistant field engineer. Location immaterial. Available fifteen days' notice. B-9408.

GRADUATE ELECTRICAL ENGINEER, 30, three years teaching electrical engineering, high voltage transmission, substation design, drafting; three years' porcelain insulators factory, electrical measurements, machinery and high voltage laboratory experience; one year research work. Ambitious, energetic, best references. Wants position with good opportunity. Available on a months' notice. Location immaterial. B-8063.

TECHNICAL GRADUATE, B. S. in electrochemical engineering, five years' experience with well known electrical manufacturing company in general engineering development and quality work. At present employed. Salary $3000. B-9717.

GRADUATE ELECTRICAL ENGINEER, eight years' experience manufacture, installation and maintenance of central and substation mechanical and electrical equipment. Desires position in construction, operation or maintenance. Available reasonable notice. B-9217.

INSTRUCTOR IN PHYSICS, 26, single, seven years' successful teaching in first grade colleges, lectures recitations, laboratory. Capable of developing new courses; three years' graduate study. Seeks connection with college offering opportunity for advancement and research toward Doctorate. Location preferred, East. B-7644.

ELECTRICAL ENGINEER, 25, single, German, graduated from a well known university abroad in 1923; one year power plant designing, one year construction, also testing experience. Desires position necessitating designing ability, and offering position for advancement. Available one week. Location immaterial. B-9312.

ELECTRICAL AND MECHANICAL ENGINEER experienced in the manufacture of electric heating appliances, small motors and household machinery. Five years in present position as assistant to chief engineer of ten million dollar concern. Have handled important research and development problems. Technical education and test experience. American, 28, married. Available thirty days, prefer New York. B-9082.

TECHNICAL GRADUATE E. E., age 27, single, with American and German technical training, desires connection with firm offering opportunity to be active in Germany. Five years' practical experience in electrical construction work of all kinds, three years' power-house and substation designing. Graduate La Salle University, salesmanship course. Enrolled student Alexander Hamilton Inst. Business Course. B-8447.

ELECTRICAL CONSTRUCTION FOREMAN, ten years' experience, age 30, married, desires position with construction company. Location immaterial. Available on reasonable notice. B-9734.

JUNIOR ENGINEER, 1923 graduate electrical engineer, two years' experience as illuminating engineer, three years' electrical testing and inspection, desires position in construction or power installation work. Would consider sales engineering position if located in East. B-8148.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED APRIL 14, 1925

ANDRESS, JOSEPH MAX, 318 West 57th St., New York, N. Y.

*ARGO, JOHN PAUL, Asst. Engineer, Electrical Dept., Memphis Power & Light Co., 16 S. Second St., Memphis, Tenn.

AUSTIN, CLARK F., Inspection & Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BAKER, FRED. CHARLES, Tester, Meter & Test Dept., United Electric Light & Power Co., 514 W. 147th St., New York, N. Y.

BAKER, KENNETH G., Advertising Manager, Century Electric Co., 1827 Pine St., St. Louis, Mo.

BALDWIN, EDWARD MANNING, President, Baldwin-Stewart Electric Co., 210 Pearl St., Hartford, Conn.

BALFOUR, ROBERT, Power Installation Foreman, Western Electric Co., Inc., 268 West 36th St., New York, N. Y., res., Bayonne, N. J.

*BATEMAN, GORDON RUSSELL, Mechanic, Maintenance Dept., Toronto Hydro Electric System, 225 Yonge St., Toronto, Ont. Can.

BEACH, A. BLAINE, Senior Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BECK, WALLACE W., Commercial Agent, Michigan Bell Telephone Co., 1365 Cass Ave., Detroit, Mich.

*BECK, WALTER, Engineer, Montgomery Elevator Co., Moline, Ill.

BELASCO, P. DAVID, Engineer, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

*BETZER, CECIL EVERETT, Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.; res., Kenosha, Wis.

BIHLER, GEORGE, Division Superintendent, Utah Power & Light Co., Bingham Canyon, Utah.

BOHNER, CLARENCE W., Draughtsman, New York Edison Co., 44 E. 23rd St., New York, N. Y.

BOOTH, ROBERT B., Electrical Draftsman, Alabama Power Co., Brown-Marx Bldg., Birmingham, Ala.

*BOWMAN, PERCY FRANK, Specification Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*BOYDEN, WILSON GORDON, Electrical Inspector, Liberty Electric Corp., Stamford; res., Greenwich, Conn.

*BROCKINGTON, HARRY GUSTAF, Electrical Salesman, Schiefer Electric Co., Inc., 595 Ellicott Sq., Buffalo, N. Y.

BROOKS, JOSIAH ALEXANDER, Engineering Assistant, Brooklyn Edison Co., Inc., Pearl & Willoughby Sts., Brooklyn, N. Y.

BROWN, GEORGE E., General Electric Co., 84 State St., Boston; res., Andover, Mass.

*BROWN, NOLAND WALDO, Engineering, General Electric Co., Pittsfield, Mass.

BROWNLEE, ALLAN LOCKHART, Foreman, Instrument Testing, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.

BURNHAM, CALTON MONROE, Jr., Exciter Operator, Commonwealth Edison Co., Chicago, Ill.

CADWELL, FRANK L., Relay & Circuit Inspector, New York Telephone Co., 53 Park Place, New York; res., Brooklyn, N. Y.

CANTILINA, NICHOLAS, Instructor, Practical Electricity, Paterson Vocational School, Summer & Ellison Sts., Paterson, N. J.

CAPOCEFALO, JOHN A., Shop Foreman, Westinghouse Elec. & Mfg. Co., Bruce Ave. & Seymour St., Bridgeport, Conn.

CARLSON, PAUL, Engineer, Underground Elec. Distribution, St. Paul Gas Light Co., St. Paul, Minn.

CARLSON, R. JOHN, Cable Inspector, Public Service Corp., 15 E. Park Place, Newark, N. J.; res., Brooklyn, N. Y.

CARPENTER, J. F., Inspector, Dist. Dept., Northern States Power Co., 807 Lincoln Bank Bldg., Minneapolis, Minn.

CASTLE, CHRISTIAN V., Delaware & Atlantic Tel. & Tel. Co., 5th & Market Sts., Camden, N. J.

CAVAGNARO, A. EMILE, Checker, Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.

CHAPMAN, ARTHUR AUGUSTINE, Partner, Peer-Chapman Electrical Co., Yorkton, Sask., Can.

CHRISMAN, DON ELMO, Watch Electrician, Commonwealth Edison Co., 3501 So. Crawford Ave., Chicago, Ill.

CHULSTROM, JOHN, Mechanical Draftsman, Western Union Telegraph Co., 195 Broadway, New York, N. Y.

CLANCY, EDWIN D., Service Engineer, Westinghouse Elec. & Mfg. Co., Bruce Ave. & Seymour St., Bridgeport, Conn.

*CLARKSON, CHARLES NEWCOMB, Tester, San Joaquin Div., Pacific Gas & Electric Co., Modesto, Calif.

*CLEMENT, ANDREW WEIR, Student, University of Washington, Terminal Station P. O., Seattle, Wash.

COLSON, LAUREN GILBERT, Supervisor Line Extension Estimators, Commonwealth Edison Co., 72 West Adams St., Chicago, Ill.

COMPTON, KARL ROSCOE, Head Relief Operator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
CONNORS, JOHN JAMES, Engineering Dept., Interborough Rapid Transit Co., 98th St. & 3rd Ave., New York, N. Y.
CONRAD, ALVIN ABRIN, Engineering Inspector, Overhead Engg. Dept., Northern Ohio Traction & Light Co., Akron, Ohio.
COOPER, ROBERT LESLIE, Vice-President, Baldwin-Stewart Electric Co., 210 Pearl St., Hartford, Conn.
CRONIN, D. F., Chief Electrician, Cherry River Paper Co., Richwood, W. Va.
CRYDER, JAMES W., Field Engineer, Pittsburgh Transformer Co., 1007 Arch St., Philadelphia, Pa.
DAVIS, URIAH, Load Dispatcher, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Park Ridge, Ill.
*DEHLS, FREDERICK, Electrical Engineer, Apparatus & Equipment Dept., All America Cables, Inc., 89 Broad St., New York, N. Y.
DE MORAES, MARCIO S., Electrical Engineer, Acme-International X-Ray Co., Banco Hollandez da America do Sul, Rio de Janeiro, Brazil, So. Amer.
*DOBBS, HARRY COLLISTER, Asst. Purchasing Agent, Puget Sound Pr. & Lt. Co., 470 Pittock Block, Portland, Ore.
*DONALDSON, ROBERT JENNINGS, Testing Engineer, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
DOTY, ALFRED F., Electrical Engineer, Westinghouse Elec. & Mfg. Co., Bridgeport, Conn.
DOUGHTY, GEORGE FRANCIS, Sales Engineer, Simplex Wire & Cable Co., 1328 Broadway, New York, N. Y.
*DOWNING, LLOYD H., Sales Engineer, Century Electric Co., 620 Witherspoon Bldg., Philadelphia, Pa.
DUNCAN, JAMES ARMSTRONG, Asst. Engineer, Research Bureau, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn, N. Y.
*DUNLEVY, JEROME N., Line Estimator, Overhead Extensions, Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
ELLERMAN, ARTHUR, Salesman, Moloney Electric Co., St. Louis; for mail, Kansas City, Mo.
*ELLIOTT, RICHMOND K., Line Extension Estimator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
EMMONS, HERBERT ALCEMUS, Traffic Engineer, Western Union Telegraph Co., 195 Broadway, New York, N. Y.
EVANS, HARLECH R., Student, Elec. Engg. Dept., Pratt Institute, 128 Willoughby St., Brooklyn, N. Y.
EVERITT, WILLIAM LITTELL, Instructor, Elec. Engg. Dept., University of Michigan, W. Engg. Bldg., Ann Arbor, Mich.
FALEY, WILLIAM F., Transmission & Interference Inspector, Tri-State Tel. & Tel. Co., 8th & Cedar Sts., St. Paul, Minn.
FALK, KASPER KAUFFELDT, Draftsman, Engg. Inside Plant Div., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
FARMER, RAYMOND A., Transmission Engineer, Northern States Power Co., 806 Lincoln Bank Bldg., Minneapolis, Minn.
*FETSCH, JOSEPH T., Jr., Student Engineer, General Electric Co., Schenectady, N. Y.
FITCH, JAMES C., Senior Clerk, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*FIX, FREDERICK WILLIAM, Jr., Power Supervisor's Assistant, Public Service Co. of No. Illinois, 72 W. Adams St., Chicago; res., Kenilworth, Ill.
FREILE, ORMOND, Technical Advertising Writer, McGraw Hill Co., 36th St. & 10th Ave., New York, N. Y.
FRY JACOB R., Engineer, Engg. Dept., Western Electric Co., Inc., 463 West St., New York, N. Y.
*GABRIELIDES, ALEXANDER PETER, 29 B Canningos Ave., Athens, Greece.
*GLICK, JUSTUS EDWARD, Student, University of Virginia, University, Va.
GOLDBERG, HARRY JULIUS, Draftsman, Station Constr. Dept., Toronto Hydro-Electric System, Toronto, Ont., Can.
GRIMM, WALTER F., Operator, Generating Station, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*GRONDORF, HERMAN, Asst. Engineer, Valuation Dept., Pacific Gas & Electric Co., 245 Market St., San Francisco; res., Berkeley, Calif.
*GROPP, GEORGE JOHN, Electrical Inspector, Brooklyn Edison Co., 561 Grand Ave., Brooklyn; res., Stapleton, N. Y.
*GUSTAFSON, ORIEN ALGET, Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.
*HAJOS, EUGENE, Electrical Designer, Radio Corp. of America, 66 Broad St., New York, N. Y.
HALL, RUSSELL EDMUND, Testing Dept., General Electric Co., Schenectady, N. Y.
HAMILTON, GEORGE, Jr., Electrical Supervisor, Erie Railroad Co., Jersey City; res., Bogota, N. J.
HARLAN, KENNETH G., Electrical Engineer, Prefontaine Bldg., Seattle, Wash.
HARRIS, HERBERT V., Engineering Clerk, Bureau of Power & Light, 120 E. 4th St., Los Angeles, Calif.
HARTENHEIM, MAX, Chief Engineer, The Electric Generator Corp., 1704 Keenan Bldg., Pittsburgh; res., Edgewood, Pa.
HATCH, ARNOLD ROBERT, Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
HATZIMIHAIL, MICHAIL R., Electrician, Pennsylvania Railroad Co., Long Island City; for mail, New York, N. Y.
HAU, LAWRENCE JOHN, Line Extension Estimator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
HAUCK, CARL F., Checking Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*HAWKINS, HARVEY CARROLL, Transmission Engineer, Northwestern Bell Telephone Co., 420, 3rd Ave. S., Minneapolis, Minn.
HERVEY, WILLIAM KENNEDY, Checking Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Oak Park, Ill.
*HIERONYMUS, REX E., Head of Turbine Test, General Electric Co., Schenectady, N. Y.
HILLIARD, M. C., Asst. Supt., Substation Operation, Southern California Edison Co., Los Angeles, Calif.
*HINCKLEY, ROGER MYRON, Asst. Electrical Engineer, Dwight P. Robinson & Co., Inc., 3722 5th Ave., Pittsburgh, Pa.
HODNETTE, JOHN K., Engineer, M. & P. Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Edgewood, Pa.
HOFFHAUS, HENRY BENJAMIN, Underground Engineer, Des Moines Electric Co., 802 Locust St., Des Moines, Iowa.
*HOFFMAN, LOUIS BENJAMIN, 28 Gates Ave., Montclair, N. J.
HOLLEY, BURTON D., Student, Chicago Central Station, Commonwealth Edison Co., 22nd & Fisk Sts., Chicago, Ill.
HONYCHURCH, AUBREY WALTER, Inspector, Elec. Engg. Dept., Brooklyn Edison Co., 561 Grand Ave., Brooklyn, N. Y.
*HORGAN, FRANCIS JOSEPH, Student, 239 Broadway, Newport, R. I.
*HOWES, EDGAR THATCHER, 337 N. Mathews St., Los Angeles, Calif.
HOYNCK, LEE A., Engineer, Bemis Bros. Bag Co., 601 S. 4th St., St. Louis, Mo.
HUNT, WILLIAM THOMAS, Manager, Northern Electric Co., Ltd., Cor. 6th and Osler Sts., Regina, Sask., Can.
INOUYE, GORO, Electrical Engineer, Hayakawa Denryoku K. K., Kaiji Bldg., Tokio, Japan; for mail, Schenectady, N. Y.
IWAFUCHI, YASUJI, Electrical Engineer, Toho Electric Power Co., Kaiji Bldg., Tokio, Japan; for mail, Schenectady, N. Y.
*JAQUES, CLOYCE AUSTIN, Cable Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*JASPER, CRONJE, Junior Engineer, Cable Div., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
JOHNSON, FLOYD DWIGHT, Graduate Student Apprentice, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pittsburgh, Pa.
JOHNSON, HARVEY JUDD, Testing Engineer, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
JOHNSTON, FRED EARNEST, Engineer in Charge, Riverhead Sta., Radio Corp. of America, Riverhead, N. Y.
JONES, ARTHUR OWAIN, Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
JONES, ROBERT H., Electrician, Construction Dept., Brooklyn Edison Co., Brooklyn, N. Y.
KADLEC, STANLEY, Sectional Inspector, Argentine Landlines, All America Cables, Inc., Mendoza, Argentine, So. Amer.
*KALM, ARNOLD VICTOR, Electrical Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KANE, ELLIS DAVENPORT, Laboratory Testing, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.
*KAPPLE, FREDERICK RUSSEL, Student Engineer, Northwestern Bell Telephone Co., 420 Third Ave., S., Minneapolis, Minn.
KATES, WILLARD A., Engineer, Day & Zimmerman, Inc., 1600 Walnut St., Philadelphia, Pa.
KEENE, CLAIR LEAMAN, Switchboard Operator, Commonwealth Edison Co., 35th St. & Crawford Ave., Chicago, Ill.
KELLERMAN, WILLIAM C., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KELLY, CHARLES B., Load Dispatcher, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KENNEDY, ARTHUR, Transmitter Radio Operator, Radio WHN, Loews State Theatre Bldg., 1540 Broadway, New York, N. Y.; res., Paterson, N. J.
KENNEDY, RALPH BEST, Load Dispatcher, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KENYON, HARRY H., Engineer, General Electric Co., Pittsfield, Mass.
*KILLE, LINDLEY ARTHUR, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
KIRKLAND, JULIAN S., Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KJELLGREN, ERIC, Draftsman, General Electric Co., Pittsfield, Mass.
KOMENDANTOFF, DEMETRIUS ALEXANDER, Asst. Chief Engineer, Optical Dept., Obukof Steel Shop, Obukowo, Leningrad, Russia.
*KRAUSE, CHARLES E., Ass't. Professor, Elec. Engg. Dept., Oklahoma Agricultural & Mechanical College, Stillwater, Okla.
*KUDER, BERNARD, Technical Assistant to Chief of Test, Consolidated Gas, Electric Light & Power Co., Balitmore, Md.
KUNKEL, WILLIAM RICHARD, Load Dispatcher, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KVIST, ARON E. K., Drafting Room, General Electric Co., Pittsfield, Mass.

LATHAM, IRVING J., Watch Electrician and Operator, Commonwealth Edison Co., 3501 S. Crawford Ave., Chicago, Ill.

*LAWRENCE, JOSEPH D., Jr., Asst. Supervisor of Construction, Kentucky & West Virginia Power Co., Sprigg, W. Va.

*LEAVITT, RONALD BOUTON, Estimator, Claude Neon Lights, 318 E. 32nd St., New York, N. Y.

*LEHMAN, LYLE G., Power Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

*LEWIS, ERVIN H., Trouble Dispatcher, Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston; res., Newtonville, Mass.

LYON, EARLE DeFIELD, Supervisor of Estimating Engineers, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Wilmette, Ill.

MACHA, AUGUST, Foreman, Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio.

MACKOFF, PAUL MARTIN, Machine Designer, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.

*MARTIN, FLOYD M., Instructor, Mechanics Institute, Rochester, N. Y.

*MARTIN, PAUL STOWELL, Inspector, Electrical Power Meters, New England Power Co., 35 Howard St., Worcester, Mass.

*McBROOM, H. ELLIOTT, Load Dispatcher, Hydro-Electric System, Duncan & Nelson Sts., Toronto, Ont., Can.

McCALLUM, VERNI ERNEST, Checking Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

McNARY, JAMES C., Asst. U. S. Radio Inspector, Dept. of Commerce, 405 Federal Bldg., Detroit, Mich.

MEISTER, JOHN B., Junior Engineer, Commonwealth Edison Co., 2745 Lincoln Ave., Chicago, Ill.

*MELCHER, HARVEY ROCKEFELLER, Student, University of Wisconsin, 168 Prospect Ave., Madison; res., Wisconsin Rapids, Wis.

*MERRITT, M. STEPHENS, Drafting & Field Test, Engg. Dept., Alabama Power Co., Birmingham, Ala.

*MEYER, WILLIAM PETER, Salesman & Installation, Radio Sets, Murdock, Neb.

MILLS, LYLE STAFFORD, 71 E. Elm St., Chicago, Ill.

MOFFATT, PAUL KIRBY, Asst. Engineer, Distribution Dept., Memphis Power & Light Co., 12-16 S. 2nd St., Memphis, Tenn.

*MOONEY, ROBERT HAINES, Engineer, Commonwealth Power Corp., Jackson, Mich.

MOOR WILLIS G., Chief Electrician, Station No. 3, Commonwealth Edison Co., 3501 S. Crawford Ave., Chicago, Ill.

*MORRILL, WAYNE J., Engineer, Fractional H. P. Engg. Dept., General Electric Co., Fort Wayne, Ind.

MUELLER, FRED G., Tester, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.

MYLES, JOHN A., Operating Electrician, Commonwealth Edison Co., 25th & Quarry Sts., Chicago, Ill.

NEAL, CHESTER T., Patent Lawyer, C. D. Tuska, Hartford, Conn; for mail, Springfield, Mass.

NOBLE, RAMON, Jr., General Foreman, Comerio Plants, Porto Rico Railway, Light & Power Co., Comerio Falls, Bayamon, P. R.

NOREN, HARRY E., Charge of Testing Laboratory, Public Service Co. of No. Illinois, 908 Clark St., Evanston; res., Chicago, Ill.

NORTON, HAROLD MILLER, Electrical Engineer, General Electric Co., 100 Woodlawn Ave., Pittsfield, Mass.

O'DONOGHUE, ALOYSIUS STANISLAUS, Asst. Engineer, The Cleveland Union Terminals Co., 1209 Ulmer Bldg., Cleveland, Ohio.

*PARR, JAMES FLOYD, Electrician, Stevens & Wood, Platte City, Mo.

PATES, ARTHUR J., Engineering Supervisor, Chesapeake & Potomac Telephone Co., 725 13th St., Washington, D. C.

PHILIPPOV, JOHN DEMETRIUS, Asst., Polytechnic Institute of Leningrad, Lesnoi, Sosnovka, Leningrad, Russia.

PICKELLS, CHARLES WILLIAM, Jr., Engineering Assistant, New York & Queens Electric Light & Power Co., Lawrence & Grove Sts., Flushing, N. Y.

*PLANAS, EDWARD JOSPEH, Instructor; New York Electrical School, 39 W. 17th St., New York, N. Y.

*PLATIS, CHRIS S., 64 W. 3rd South St., Salt Lake City, Utah.

POSS, JOHN, Jr., Electrician, Brooklyn Edison Co., 360 Pearl St., Brooklyn; res., Maspeth, N. Y.

PRUSMAN, CLYDE ADELBERT, Checking Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

PULLEN, CLAUDE ETHELBERT, President & General Manager, Pullen-Zoll Electric Co., 64 W. Flagler St., Miami, Fla.

*RAFUSE, IRAD STENNETT, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

*RATCLIFF, HORACE HUSSEY, Jr., Graduate Student, Educational Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

RINEHART, JOHN R., Chief Operator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

RINGDAHL, HANS OSKAR, Radio Electrician, F. A. D. Andrea, Inc., 421 E. 135th St., New York, N. Y.

ROMIG, FREDERIC WOLLE, Elec. Construction Bureau, Brooklyn Edison Co., 561 Grand Ave., Brooklyn; res., Stapleton, N. Y.

*ROSS, ROBERT VAN GILDER, Tester, Westinghouse Elec. & Mfg. Co., 224 Green St., Wilkinsburg, Pa.

ROSSET, MARCEL J., Draftsman, Brooklyn Edison Co., Brooklyn, N. Y.

*ROTHEN, EDWARD M., Electrical Engineer,, Russell & Stoll Co., 53 Rose St., New York, N. Y.

RUSH, I. L. Asst. Engineer, Overhead Extensions, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*RYAN, EUGENE A., Estimating Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SALLE, W. HEROLD, Engineering, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SAMSON, JONAS JOHN, Sub-station Operating, Congress St. Substation, Commonwealth Edison Co., Chicago, Ill.

SANDERSON, G. L., City Electrical Inspector, City Building Dept., City Hall, Akron, Ohio.

SCHLASMAN, WILLIAM HENRY, Technical Employee, American Tel. & Tel. Co., 114 Court St., New Haven, Conn.

SCHRANK, WILLIAM H., Inspector, Brooklyn Edison Co., 561 Grand Ave., Brooklyn, N. Y.

SCHULTZ, ERICH BRUNO EWALD, Power House Electrician, California Edison Co., Power House No. 1, Big Creek, Calif.

SCHWAB, CHARLES BELT, Ohio Public Service Co., Massillion, Ohio.

*SCHWARTZ, LEON, Electrical & Mechanical Contractor, 711 Coster St., New York, N. Y.

SCOTT, DAVID, Electrical Superintendent, J. G. White Engineering Corp., 43 Exchange Place, New York; res., New Brighton, N. Y.

SEIBERT, ROBERT H., Engineer, Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

SHEA, EDWARD C., Manager, Radio Dept., The Interstate Utilities Co., 424 Hutton Bldg., Spokane, Wash.

SHEEHAN, THOMAS, Chief Engineer, E. J. Murphy Co., 317 Main St., Springfield, Mass.

SHERWOOD, BERTRAND C., Specification Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SILVERS, RAYMOND C., Dept. of Operation & Engineering, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

SIMMONS, FORREST CHARLES, Engineer, South-Eastern Underwriters Association, Atlanta, Ga.

SIMPSON, HORACE WILLIAM, Telephone Switchboard Installer, Bell Telephone Co. of Canada, Toronto, Ont., Can.

SIMS, WILLARD D., Supt., Hydro-Elec. Plants, Porto Rico Railway, Light & Power Co., San Juan; res., Bayamon, P. R.

SINGH, SURAIN, Electrical Tester, Meter & Tests. Dept., Duquesne Light Co., 2101 Beaver Ave., N. S., Pittsburgh, Pa.

SMITH, HAROLD EDWIN, Supervisor, Circuit Engg., Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Naperville, Ill.

*SMITH, KILBURN MILLER, Engineer, Circuit Design, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*SMITH, THEODORE LOWNDES, 79 S. Main St., South Norwalk, Conn.

SPOEHRER, HERMANN FRED, Asst. to Electrical Superintendent, McClellan & Junkersfeld, Inc., Cahokia Power Plant, Cahokia, Ill.; for mail, St. Louis, Mo.

*STEARNS, KENNETH RUSSELL, Graduate Student, Worcester Polytechnic Institute, Worcester, Mass.

STEELE, THOMAS, Electrical Superintendent, Yorkton Municipal Power Plant, Yorkton, Sask., Can.

STELZER, JAMES GLARUM, Specification Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Maywood, Ill.

STOCKING, S. IRVIN, Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

STOHLQUIST, GUST. ARNOLD, Draftsman, Northern Ohio Traction & Light Co., Akron, Ohio.

TRACY, CHARLES RAYMOND, Illuminating Engineer, The Penna-Ohio Power & Light Co., Youngstown, Ohio.

VAN de WATER, JOHN WALKER, Engineer, Western Electric Co., Inc., 268 W. 36th St., New York; res., Hastings-on-Hudson, N. Y.

*VAN LEAR, GLENWOOD MICHAEL, Tester, United Electric Lt. & Pr. Co., 130 East 15th St., New York, N. Y.

WAGNER, CHARLES P., Municipal Lighting Engineer, Northern States Power Co., 807 Lincoln Bank Bldg., Minneapolis, Minn.

WAHLQUIST, HUGO W., Asst. Engineer, Northern States Power Co., 809 Lincoln Bank Bldg., Minneapolis, Minn.

WALSHE, JOHN MARSHALL, Sanatorium, Fort Qu'Appelle, Sask., Can.

WARNER, JOE H., Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*WARREN, ROBERT De BEVOISE, Engg. Dept., All America Cables, 89 Broad St., New York; res., Hollis, N. Y.

WHIDDEN, WILL HENRY, General Superintendent of Plant, Trinidad Consolidated Telephones, Ltd., 58 Frederick St., Port of Spain, Trinidad, B. W. I.

*WHITE, ERNEST, Fieldman, Outside Plant Engg. Dept., Southern Calif. Telephone Co., 740 S. Olive St., Los Angeles; res., Glendale, Calif.

WILLIAMS, RALPH D., Equipment Engineer, Michigan Bell Telephone Co., 1365 Cass Ave,. Detroit, Mich.

WINANS, JAMES DUSENBERRY, Engineering Assistant, Public Service Production Co.' 80 Park Place, Newark; res., Summit, N. J.

WOODBURY, PAUL D., Salesman, Westinghouse Elec. & Mfg. Co., 150 Broadway, New York, N. Y.

WOODMANCY, WALTER THORPE, Electrical Engineer, Crecelius & Phillips, 1517 Union Trust Bldg., Cleveland, Ohio.
WYATT, EDWIN A., General Foreman, Commonwealth Edison Co., 72 W. Adams St.. Chicago, Ill.
*WYLIE, WARD L., Job Supervisor, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*ZINDER, HANINA, Exciter Operator, Commonwealth Edison Co., 22nd & Fisks Sts., Chicago, Ill.; res., Racine, Wis.
Total 219
*Formerly Enrolled Students

ASSOCIATES REELECTED APRIL 14, 1925

AHLSTROM, WALTER, General Foreman, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
ANDREWS, JOHN KENDIG, Transformer Engg. Dept., General Electric Co., Pittsfield, Mass.
ASHE, MICHAEL J., Electical Test Engineer, Chile Exploration Co., Chuquicamata, Chile, So. Amer.
BARING, JOHN W., Testing Engineer, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
CREELMAN, ADAM, Plant Engineer, Eastern Steel Casting Co., Ave. L & Edwards St., Newark; res., East Orange, N. J.
DUCHARME, FRANCIS L., Electrical Engineering, Canadian & General Finance Co., Ltd., 357 Bay St., Toronto, Ont., Can.
FARNELL, WILLIAM CLEMENT FOSTER, Supervisor, Engineering Service, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Rutherford, N. J.
HALL, OWEN THACHER, Manager, The Packard Electric Co., 1926 Edmondson Ave., Baltimore, Md.
JOHNSON, FREDERICK B., Testing Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
KLEENE, WALTER F., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
La MOREE, CLAUDE DeWITT, Member of Firm, Clapp & LaMoree, 310 E. 4th St., Los Angeles, Calif.
PERRY, LUTHER P., General Commerical Manager, Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.

MEMBERS ELECTED APRIL 14, 1925

CAREY, CHARLES EDWARD, Manager, Engg. Div., Westinghouse Elec. & Mfg. Co., Seattle, Wash.
ETTLINGER, ELI, Asst. Electrical Engineer, Union Electric Light & Power Co., 315 N. 12th Blvd., St. Louis, Mo.
GAGER, E. H., Asst. Supt., Maintenance Div., Substation Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
GIROUX, CARL HUNTING, Electrical Engineer, U. S. Engineer Dept., Munitions Bldg., Washington, D. C.

MEMBERS REELECTED APRIL 14, 1925

BARSTOW, WILLIAM AUGUSTUS, Master Electrician, Navy Yard, Mare Island; res., Vallejo, Calif.
WEDDERSPOON, WILLIAM CARRICK, Electrical Engineer, Carrick Wedderspoon, Ltd., 236 Tuam St., Christchurch, New Zealand.

TRANSFERRED TO GRADE OF MEMBER APRIL 14, 1925

BAKER, GEORGE C., Assistant Engineer in Charge of Planning Division, Brooklyn Edison Co., Brooklyn, N. Y.
HOWARD, HENRY GEORGE, Chief Engineer, Cia Chilena de Electricidad, Santiago, Chile, So. Amer.
ISAACSON CHARLES B., Electrical Engineer, All American Cables, Inc., New York, N. Y.
LOFTUS, PETER F., Consulting Electrical Engineer, Timblin, Pa.
NEIN, WILLIAM C., Vice-President and Chief Engineer, Sewickley Electric Mfg. Co., Sewickley, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held April 6, 1925, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

EALES, HERBERT W., Chief Electrical Engineer, Union Electric Light & Power Co., St. Louis, Mo.
KEHOE, ARTHUR H., Electrical Engineer, United Electric Light & Power Co., New York, N. Y.
KING, MORLAND, Professor of Electrical Engineering and Head of Department, Lafayette College, Easton, Pa.
WHITNEY, RICH D., Professor of Electrical Engineering and Head of Department, Syracuse University; Consulting Engineer, Bureau of Gas & Electricity, Syracuse, N. Y.

To Grade of Member

DENTON, A. PENN, Electrical Engineer, Denton Engineering & Construction Co., Kansas City, Mo.
DIEFENDAHL, HENRY O., Instructor of Electrical Engineering, New York Electrical School, New York, N. Y.
FREYGANG, WALTER H., Engineer & Manager of Manufacturing and Sales, Walter Kidde & Company, Inc., New York, N. Y.
HALL, WILLIAM M., Assistant Superintendent, Hell Gate Power Station, New York, N. Y.
HAMMOND, HARRY B., New York Manager, Rockbestos Products Corp., New York, N. Y.
HUSSEY, ROWLAND M., Electrical Department, Superintendent, Jones & Laughlin Steel Corp., Woodlawn, Pa.
MACY, RALPH G., Chief Engineer, Socony Burner Corp., Brooklyn, N. Y.
MERRILL, WARREN C., Engineer, Pacific Tel. & Tel. Co., San Francisco, Calif.
OTTEN, HENRY, Jr., Assistant Engineer, Economics, Interborough Rapid Transit Co., New York, N. Y.
PALME, ARTHUR, Electrical Engineer, General Electric Co., Pittsfield, Mass.
RANDOLPH, ALSTYN F., Assistant to Superintendent of Street Department, Public Service Production Co., Newark, N. J.
SCOTT, BERNARD W., Assistant to Electrical Engineer, American Woolen Co., Andover, Mass.
SPARKES, HARRY P., Meter & Transformer Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1925.

Anderson, C. H., (Member), Wagner Electric Corp., St. Louis, Mo.
Atherton, A., Western Union Telegraph Co., New York, N. Y.
Barnes, E. C., C. M & St. Paul Railway, Hyak, Wash.
Bary, C., Philadelphia Electric Co., Philadelphia, Pa.
Bell, J. B., General Electric Co., Philadelphia, Pa.
Blair, B. R., Western Electric Co., Inc., New York, N. Y.
Bodeker, C. C., Murrie & Co., New York, N. Y.
Bollinger, C. H., Murrie & Co., New York, N. Y.
Booth, F. W., Toronto Hydro-Electric System, Toronto, Ont., Can.
Bootes, H. V., J. L. Murrie & Co., New York, N. Y.
Bradford, J. L., (Member), Brighton Laboratories, Inc., Newark, N. J.
Bradford, L. R., Bradford Armature Works, East St. Louis, Ill.
Brieger, A., New York Edison Co., New York, N. Y.
Brisbois, E., Borroughs Adding Machine Co., Detroit, Mich.
Brokenshire, W. S., Jr., Pennsylvania Power & Light Co., Allentown, Pa.
Brown, J. W., Chandeysson Electric Co., St. Louis, Mo.
Brown, L. H., Western Electric Co., Inc., Chicago, Ill.
Bull, C. B. (Member), Brooklyn Edison Co., Brooklyn, N. Y.
Burnett, H. D., Canadian General Electric Co., Ltd., Toronto, Ont., Can.
Carlton, F. H., General Electric Co., Schenectady, N. Y.
Carter, C. L., Virginia-Western Power Co., Charlottesville, Va.
Chartier, H. S., Fulton County Gas & Electric Co., Gloversville, N. Y.
Chilcott, E. R., Bureau of Power & Light, City of Los Angeles, Los Angeles, Calif.
Christenson, R. H., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Clark, C. N., Kansas City Power & Light Co., Kansas City, Mo.
Clark, F. P., Wagner Electric Corp., St. Louis, Mo.
Coffin, D. D., General Electric Co., Pittsfield, Mass.
Concha-Goubert, A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Cormier, A. L., Fry-Fyter Co., Dayton, Ohio
Coyle, H. S., Ohio Bell Tel. Co., Cleveland, Ohio
Cropper, R. E., Canadian Westinghouse Co. Ltd., Toronto, Ont., Can.
Crowder, H. G. Y., B. C. Electric Railway Co., Ltd., Vancouver, B. C.
Davies, M., C. H. E. Williams Co., Ltd., Vancouver, B. C.
Davis, H. S., Public Service Production Co., Newark, N. J.
Davis, J. H., Bureau of Power & Light, Los Angeles, Calif.
Deardorff, J. H., Western Electric Co., Ltd., Cicero, Ill.
Deitrich, E. E., C. B. Hawley & Co., Camp No. 2, Oakland, Md.
de Koning, T., Brooklyn Edison Co., Brooklyn, N. Y.
De Young, L. W., Proprietor, The Electric, Inglewood, Calif.
Douthwaite, K., Puget Sound Power & Light Co., Snoqualmie, Wash.
Drinkhouse, W. H., The Cutter Electrical & Mfg. Co., Philadelphia, Pa.
Druschky, R. F., Sales Engineer, 3029 Locust St., St. Louis, Mo.
Dryar, H. A., Philadelphia Electric Co., Philadelphia, Pa.
Eaden, N., Pacific Tel. & Tel. Co., Seattle, Wash
Eging, H. B., The Electrical Controller & Mfg. Co., Cleveland, Ohio
Ehmke, H. C., Jr., Moline Implement Co., Moline, Ill.
(Applicant for re-election.)
Engle, K. D., Dubilier Condenser & Radio Corp., New York, N. Y.
Eustace, Mary M., Western Union Telegraph Co., New York, N. Y.
Fairman, F. E., Penna. Water & Power Co., Baltimore, Md.
Farrell, J. R., General Electric Co., Philadelphia, Pa.
Feller, W. J., Hub Engineering Corp., New York, N. Y.
Finlaw, J., Philadelphia Electric Co., Philadelphia, Pa.

Fitzgerald, F. G., Western Electric Co., Inc., New York, N. Y.
Forkner, E. A., Wagner Electric Corp., St. Louis, Mo.
Forsberg, E. J., St. Paul Gas & Electric Co., St. Paul, Minn.
Forster, R., New York Telephone Co., New York, N. Y.
Carcia, S. E. Phoenix Utility Co., Cardenas, Cuba
Garms, P., Electrical Testing Laboratories, New York, N. Y.
Gilbert, H. P., Western Union Telegraph Co., New York, N. Y.
Glover, F. M., New York Central R. R. Co., New York, N. Y.
Gustafson, C. J., Western Electric Co., Inc., New York, N. Y.
Hannaford, E. S., Georgia School of Technology, Atlanta, Ga.
Harmon, J. J., Southwestern Bell Tel. Co., St. Louis, Mo.
Harrington, M. J., Burroughs Adding Machine Co., Detroit, Mich.
Harvey, A. L., E. W. Clarke Engineering Corp., Chattanooga, Tenn.
Headman, S., (Member), Tucson Gas, Elec. Lt. & Pr. Co., Tucson, Ariz.
Hemeter, L. H., Western Electric Co., Inc., New York, N. Y.
Herman, J. M., Freed-Eisemann Radio Corp., Brooklyn, N. Y.
Herrmann, C. S., Jr., New York Telephone Co., New York, N. Y.
Hilliard, C. W., United Electric Light & Power Co., New York, N. Y.
Hoffmann, E. L., Southwestern Bell Tel. Co., St. Louis, Mo.
Holt, E. F., Transelectric Co., Chicago, Ill.
Hooper, A. W., CKC Station, Leader Publishing Co., Ltd., Regina, Sask., Can.
Hopewood, P., Murrie & Co., Inc., New York, N. Y.
Horgan, J. L., Brooklyn Edison Co., Brooklyn, N. Y.
Hover, E. W., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Humphrey, W. A., Pratt Institute, Brooklyn, N. Y.
Johnson, F., Wagner Electric Corp., St. Louis, Mo.
Johnson, M. E., Stromberg-Carlson Tel. Mfg. Co., Rochester, N. Y.
Jones, M. C., General Electric Co., Schenectady, N. Y.
Kaestner, W. F., Murrie & Co., New York, N. Y.
Kauer, E., (Member), C. E. Mfg. Co., Inc., & Providence Distributing Co., Providence, R. I.
Kenny, C. H., (Member), Brooklyn Edison Co., Brooklyn, N. Y.
Klasek, F. A., Hub Engineering Corp., New York, N. Y.
Klotz, R. W., The Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Krueger, R. E., Mo. Pacific Railway, St. Louis, Mo.
Lassen, E. U., The Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Le Ghait, E. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Lock, M. K., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Long, W. G., Western Electrical Instrument Corp., Newark, N. J.
Lowry, C. J., Connecticut Mills Co., Danielson, Conn.
Lynn, J. E., Northern Ohio Traction & Light Co., Akron, Ohio
Mackerras, A. P., General Electric Co., Schenectady, N. Y.
Macintyre, M., Victor Talking Machine Co., Camden, N. J.
Mankin, H. A., Michigan Bell Tel. Co., Detroit, Mich.
McFeeder, E. S., General Electric Co., Philadelphia, Pa.
McIntosh, C., Buffalo General Electric Co., Buffalo, N. Y.
Meier, C., Chandeysson Electric Co., St. Louis, Mo.
Mersfelder, J. H., Jr., New York Telephone Co., New York, N. Y.
Miller, W. E., New York Electrical School, New York, N. Y.
Moody, N. T., N. Y., N. H., & H. R. R. Co., Stamford, Conn.
Morgenstern, R. V., Western Union Telegraph Co., New York, N. Y.
Morris, A. K., Burroughs Adding Machine Co., Detroit, Mich.
Moses, G. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Naudain, L. D., New York Shipbuilding Corp., Camden, N. J.
Newell, A. B., Washington University, St. Louis, Mo.
Nordstrom, J. F., General Electric Co., Pittsfield, Mass.
Oschrin, L., 828 Gerard Ave., New York, N. Y.
Park, H. S., Bureau of Fire Alarm & Police Tel., Los Angeles, Calif.
Phillipps, M. W., Ojai Power Co., Ojai, Calif.
Poage, F. C., Idaho Power Co., Boise, Idaho
Prieve, H. F., Burroughs Adding Machine Co., Detroit, Mich.
Reilly, E. L., Pittsburgh Transformer Co., Pittsburgh, Pa.
Ritter, A. S., Commonwealth Edison Co., Chicago, Ill.
Rogoff, J., Salto Textile Co., Bridgeport, Conn.
Ross, R. H., (Member), American Tel. & Tel. Co., New York, N. Y.
Row, B. J., General Iron Works, Englewood, Colo.
Rudnicki, T. F., United Electric Light & Power Co., New York, N. Y.
Sandercock, R., Dept. of Telephones, Swift Current, Sask., Can.
Saul, H. K., Seneca Electrical Equipment Co., Morgantown, W. Va.
Schell, J. E., General Electric Co., Buffalo, N. Y.
Schmolck, R., Automatic Electric Co., Chicago, Ill.
Scott, G. R., Jeffery-DeWitt Insulator Co., Chicago, Ill.
Seybt, H. B., General Electric Co., St. Louis, Mo.
Shadbolt, F. H., Murrie & Co., New York, N. Y.
Shannon, J. H., (Member), Radio Corp. of America, New York, N. Y.
Sharp, F. B., De Forest Phonofilm Corp., New York, N. Y.
(Applicant for re-election.)
Shearer, L. D., Reading Co., Reading, Pa.
Sherborne, F. G., (Member), Pacific Mills, Ltd., Ocean Falls, B. C.
(Applicant for re-election.)
Sherman, C. C., Murrie & Co., Inc., New York, N. Y.
Sjoholm, G., Burroughs Adding Machine Co., Detroit, Mich.
Slaboski, H. T., Penna. Power & Light Co., Hamilton, Pa.
Smith, A. T., Burroughs Adding Machine Co., Detroit, Mich.
Smith, H. C., Bell Telephone Co., Philadelphia, Pa.
Sobey, J. H., Wisconsin Telephone Co., Eau Claire, Wis.
Stanton, E. J., (Member), Laclede Gas Light Co., St. Louis, Mo.
Steven, J. C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Talmage, T. DeW., Cincinnati & Suburban Bell Tel. Co., Cincinnati, Ohio
Taylor, P., Thomas E. Murray, Inc., New York, N. Y.
Ternow, H. G., Pacific Tel. & Tel. Co., San Francisco, Calif.
Thirgood, C., Burroughs Adding Machine Co., Detroit, Mich.
Townsend, A., Milestone Light Plant, Milestone, Sask., Can.
(Applicant for re-election.)
Tsatsaron, N., Electrical Contractor, 321 W. 39th St., New York, N. Y.
Tugby, E. E., Bliss Electrical School, Takoma Park, Washington, D. C.
Turnbull, W., The Detroit Edison Co., Detroit, Mich.
Villatuya, R. P., Mead & Seastone, Madison, Wis.
Wagner, W. A., Hub Engineering Corp., New York, N. Y.
Wallace, E. V., American Tel. & Tel. Co., Birmingham, Ala.
Wallisch, C. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Wann, W. L., So. California Edison Co., Big Creek, Calif.
Ward, J. W., Northern Aluminum Co., Ltd., Toronto, Ont. Can.
Weiss, J. K., Long Island Railroad, Brooklyn, N. Y.
Wenzel, G. W., Northern Ohio Traction & Light Co., Akron, Ohio
Whipple, W. C., Puget Sound Power & Light Co., Seattle, Wash.
(Applicant for re-election.)
Willson, R. S., Jr., Hall Switch & Signal Co., Garwood, N. J.
Wood, B. M., New England Tel. & Tel. Co., Boston, Mass.
Woodward, A. J., Elec. Supt. & Chief Engr., City of Weyburn, Weyburn, Sask., Can.
Woodtli, E., Brooklyn Edison Co., Brooklyn, N. Y.
Wyer, S. S., Consulting Engineer, 1014 Hartman Bldg., Columbus, Ohio
Yager, O. C., Telephone Exchange, Regina, Sask., Can.
Young, D. D., American Tel. & Tel. Co., New York, N. Y.
Young, J. R., Sun Electrical Co., Ltd., Regina, Sask., Can.
Zecher, H. P., Philadelphia Rapid Transit Co., Philadelphia, Pa.
Zetka, J. B., (Member), Brightson Laboratories, Inc., Newark, N. J.

Total 166

Foreign

Arai, T., Raido Denryoku Momoyama Power Station, Nagoya, Japan
Manning, A. C., Hawaiian Philippine Co., Silay Hawaiian Central, Negros Occ., P. I.
Meacock, J. H., Express Lift Co., London, S.W. 1, Eng.
Miller, E. H., (Member), The Edison Swan Electric Co., Ltd., Middlesex, Eng.
Neander, M. T., (Member), Volhov Hydro-Elec. Pr. Plant, Volhovstroi, Russia.
Soi, H. R., (Member), Officer in charge of Water District, Kingsway, Delhi, India.
Takano, S., Elec. Engr. to Ministry of Communication, Peking, China.
Yamada, M., Daido Denryoku K. K.; For mail, Maegasu, Yatomicho, amagun, Aichi-ken, Japan.

Total 8

STUDENTS ENROLLED APRIL 14, 1925

Annas, Herbert C., University of Michigan
Barkovich, Joseph A., University of Michigan
Bean, Theron W., Stanford University
Beyer, Haim, College of the City of New York
Blom, Lucien F., College of the City of New York
Boer, Dennis M., University of Michigan
Boyd, Oliver H., University of Toronto
Carlson, McKinley S., University of Wisconsin
Crosman, Warren T., University of Colorado
Day, Edgar F., College of the City of New York
Deiratani, Samuel G., College of the City of New York
Dulitzky, Leon, College of the City of New York
East, Lawrence A. W., University of Toronto
Ford, Evert H., Stanford University
Gallagher, Paul A., Cornell University
Geis, George F., Mass. Institute of Technology
Glaza, Felix S., University of Michigan

Grace, Charles R., Ohio Northern University
Grignon, Francis J., Cornell University
Hall, Sherman M., Worcester Polytechnic Institute
Heath, Edwin A., University of Colorado
Heath, Herbert P., University of Colorado
Herson, Jacob S., College of the City of New York
Hind, Roland F., University of Colorado
Hirsch, Harry W., College of the City of New York
Hochgraf, Lester B., Rensselaer Polytechnic Institute
Hoffman, Roland A., University of Michigan
Holcomb, Harley J., Oklahoma A. &. M. College
Hostetler, Howard B., University of Michigan
Inglis, George F., University of Toronto
Johnson, George C., Missouri School of Mines & Metallurgy
Kaloyan, H. S., University of Michigan
Katranis, George J., Northeastern University
Kendall, James M., Rice Institute
Kulman, Frank E., College of the City of New York
Lloyd, Warren G., University of Toronto
McCaw, Robert F., Missouri School of Mines & Metallurgy
McDowell, Lewis G., Rensselaer Polytechnic Institute
McDuff, Murphy C., Alabama Polytechnic Institute
Melton, Benjamin S., Rice Institute
Messer, G. Elbert, University of Colorado
Miller, John F., Ohio Northern University
Patrick, Homer G., Rice Institute
Paullin, Edward M., Jr., University of Colorado
Pierce, D. Lawrence, University of Michigan
Pommer, Clifford G., Washington State College
Robertson, James A., Worcester Polytechnic Institute
Roehm, Adloph C., University of Michigan
Sayre, Ralph S., Rensselaer Polytechnic Institute
Scheel, Ralph H., University of Michigan
Seidler, Abraham, College of the City of New York
Smith, Theodore A., Stevens Inst. of Technology
Sovitzky, Stanley, Engg. School of Milwaukee
Stoops, Perry, State College of Washington
Sweany, Fay H., State College of Washington
Taylor, Hugh L., Rugby Technical School
Thomson, Howard B., Worcester Polytechnic Institute
Tinetti, John B., University of Michigan
Tyler, Kenneth G., Armour Inst. of Technology
Ward, Harold A., Jr., University of Florida
Wells, William B., Stanford University
Whatmough, Frederick R., University of Toronto
Willey, Ralph E., Purdue University
Williams E. Eugene, University of Idaho
Winslow, W. M., University of Colorado
Wolf, Harold, College of the City of New York
Wuerfel, Robert P., University of Michigan
Yaffee, Simon, Rensselaer Polytechnic Institute
Total 68

OFFICERS OF A. I. E. E. 1924-1925

President

FARLEY OSGOOD

Junior Past Presidents

HARRIS J. RYAN
FRANK B. JEWETT

Vice-Presidents

J. E. MACDONALD
EDWARD BENNETT
HERBERT S. SANDS
JOHN HARISBERGER
S. E. M. HENDERSON
HAROLD B. SMITH
H. E. BUSSEY
L. F. MOREHOUSE
WILLIAM F. JAMES
H. W. EALES

Managers

R. B. WILLIAMSON
H. M. HOBART
A. G. PIERCE
ERNEST LUNN
HARLAN A. PRATT
G. L. KNIGHT
WILLIAM M. MCCONAHEY
JOHN B. WHITEHEAD
W. K. VANDERPOEL
J. M. BRYANT
H. P. CHARLESWORTH
E. B. MERRIAM

Treasurer

GEORGE A. HAMILTON

Secretary

F. L. HUTCHINSON

Honorary Secretary

RALPH W. POPE

LOCAL HONORARY SECRETARIES

T. J. Fleming, Calle B. Mitre 519, Buenos Aires, Argentina
Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janeiro, Brazil
Charles le Maistre, 28 Victoria St., London, S. W., 1, England
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France
H. P. Gibbs, Tata Sons, Ltd., Navsari Building, Fort Bombay, India
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy
Eiji Aoyagi, Kyoto Imperial University, Kyoto, Japan
Axel F. Enstrom, 24 A Grefturegatan, Stockholm, Sweden
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa

A. I. E. E. COMMITTEES

(A list of the personnel of Institute committees may be found in the January issue of the JOURNAL.)

GENERAL STANDING COMMITTEES AND CHAIRMEN

EXECUTIVE, Farley Osgood
FINANCE, G. L. Knight
MEETINGS AND PAPERS, L. W. W. Morrow
PUBLICATION, Donald McNicol
COORDINATION OF INSTITUTE ACTIVITIES, Frank B. Jewett
BOARD OF EXAMINERS, H. H. Norris
SECTIONS, Harold B. Smith
STUDENT BRANCHES, C. E. Magnusson
MEMBERSHIP, E. E. Dorting
HEADQUARTERS, E. B. Craft
LAW, L. F. Morehouse
PUBLIC POLICY, H. W. Buck
CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT, John W. Lieb
SAFETY CODES, Paul Spencer
STANDARDS, H. S. Osborne
EDISON MEDAL, Gano Dunn
COLUMBIA UNIVERSITY SCHOLARSHIP, Francis Blossom
AWARD OF INSTITUTE PRIZES, L. W. W. Morrow

TECHNICAL COMMITTEES AND CHAIRMEN

COMMUNICATION, O. B. Blackwell
EDUCATION, Harold Pender
ELECTRICAL MACHINERY, H. M. Hobart
ELECTROCHEMISTRY AND ELECTROMETALLURGY, George W. Vinal
ELECTROPHYSICS, J. H. Morecroft
INSTRUMENTS AND MEASUREMENTS, A. E. Knowlton
APPLICATIONS TO IRON AND STEEL PRODUCTION, F. B. Crosby
PRODUCTION AND APPLICATION OF LIGHT, G. H. Stickney
APPLICATIONS TO MARINE WORK, L. C. Brooks
APPLICATIONS TO MINING WORK, F. L. Stone
GENERAL POWER APPLICATIONS, A. E. Waller
POWER GENERATION, Vern E. Alden
POWER TRANSMISSION AND DISTRIBUTION, Percy H. Thomas
PROTECTIVE DEVICES, H. R. Woodrow
RESEARCH, John B. Whitehead

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives may be found in the January issue of the JOURNAL.)

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, COUNCIL
AMERICAN BUREAU OF WELDING
AMERICAN COMMITTEE ON ELECTROLYSIS
AMERICAN ENGINEERING COUNCIL
AMERICAN ENGINEERING STANDARDS COMMITTEE
AMECICAN MARINE STANDARDS COMMITTEE
APPARATUS MAKERS AND USERS COMMITTEE
BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY
CHARLES A. COFFIN FELLOWSHIP AND RESEARCH FUND COMMITTEE
ENGINEERING FOUNDATION BOARD
JOHN FRITZ MEDAL BOARD OF AWARD
JOINT CONFERENCE COMMITTEE OF FOUR FOUNDER SOCIETIES
LIBRARY BOARD, UNITED ENGINEERING SOCIETY
NATIONAL FIRE PROTECTION ASSOCIATION, ELECTRICAL COMMITTEE
NATIONAL FIRE WASTE COUNCIL
NATIONAL RESEARCH COUNCIL, ENGINEERING DIVISION
SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION, BOARD OF INVESTIGATION AND COORDINATION
U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION
U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION
WASHINGTON AWARD, COMMISSION OF

A. I. E. E. SECTIONS AND BRANCHES

See the April issue for the latest published list. The Institute now has 49 Sections 82 Branches.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Transformers.—Bulletin 2042, 4 pp. Describes Pittsburgh single phase distribution transformers, and illustrates sizes from 25 kv-a. to 200 kv-a., 400 volts to 66,000 volts. Pittsburgh Transformer Company, Pittsburgh, Pa.

Panelboards.—Catalog 35. Describes and illustrates a complete line of safety panelboards for two fuse and single fuse codes. Frank Adam Electric Company, 3650 Windsor Place, St. Louis, Mo.

Electrical Measuring Instruments.—Catalog 15, 80 pp. Describes a wide range of instruments including voltmeters, wattmeters, voltammeters, automotive testing instruments, power factor meters, frequency indicators, radio testing sets, wave meters, current transformers, instrument transformers, etc. Jewell Electrical Instrument Company, 1650 Walnut Street, Chicago, Ill.

Panelboards.—Catalog, 48 pp., "Good Panelboard Practice." Describes and illustrates switchboards for power, light, stage lighting; lighting panelboards and cabinets, dead and live front types; metering panels; feeder distribution panels, dead and live front types; steel cabinets and pull boxes. The Superior Switchboard and Devices Co., Canton, Ohio.

Lifting Magnets.—Bulletin 107, 24 pp. Describes Ohio lifting magnets and illustrates their use in the iron and steel trades; also for magnetic separation of tramp iron and ore, cement, coal, etc., over conveyors or chutes. Numerous illustrations show applications for handling pipe in warehouses, rails, billets, etc., as well as iron, steel and scrap in bulk. The Ohio Electric & Controller Company, 5900 Maurice Ave., Cleveland, Ohio.

NOTES OF THE INDUSTRY

The Wagner Electric Corporation, St. Louis, Mo., announces the removal of its Atlanta office to 145 West Peach Tree Street, Atlanta, Ga.

The Kohlenite Products Co., Inc., manufacturer of carbon brushes for electrical machinery, have moved into its new factory located at 417 W. 28th Street, New York.

The General Electric Company has announced an average reduction of 10 per cent on standard types of polyphase induction motors in sizes from 1 to 15 h. p. inclusive, and an average of 4 per cent in sizes from 15 to 100 h. p. inclusive, both effective April 6th.

W. N. Matthews Corporation, St. Louis, Mo., recently held its annual election of officers. The following were designated: W. N. Matthews, President; Claude L. Matthews, Vice-Pres. and Treas.; James R. Kearney, Vice-Pres. and Manager of Electrical Sales; M. C. Cooley, Secretary, and Dillon T. Stevens, Director of Sales, Mechanical Painting Equipment.

Winfield H. Smith, manufacturer of speed reduction devices, formerly located at Buffalo, N. Y., has moved to Springville, N. Y. All manufacturing has been done at Springville the past seven months, and beginning May 1st the factory and office will be under one roof.

Business of the General Electric Company Increases.—Orders received by the General Electric Company for the three months ended April 1, comprising the first quarter of the present year amounted to $83,846,236, as compared with $73,487,903 in the same quarter of 1924, according to an announcement by President Gerard Swope. This is an increase of 14 per cent.

Westinghouse Gets Large Orders.—The Westinghouse Electric & Manufacturing Company has received a contract from the Commonwealth Edison Company for a frequency converter set, claimed the largest yet to be constructed. This set has a capacity of 40,000 kv-a. and will be used for tying together the Commonwealth Edison Company's 60 cycle and 25 cycle systems.

The Los Angeles Gas & Electric Company has ordered forty-two standard regulators from the Westinghouse Company, to be used on individual circuits to maintain constant voltage regulation to the consumer. Additional equipment included in the contract brings the order up to approximately $150,000.

General Electric Company Awards to Employees.—During the year 1924 awards totalling $39,531 were paid to 3,244 employees of the General Electric Company for suggestions which increase the efficiency of the company's operations. The suggestions ranged from those covering safety devices for the protection of workers to ideas on improved methods of manufacturing electrical apparatus, and the awards ranged from $1.00 to $1,000. In 1923, $22,988 was distributed to 1,752 employees, and the highest award was $500. Of all the suggestions, over 21.7 per cent were accepted. In 1924 the percentage of acceptances was 36, showing a large increase in the interest and awards in the suggestion system over the preceding year.

Chas. Cory & Son, Inc., New York, manufacturers of electric valve controls, power plant signal systems, load indicators and interlocks, have appointed Harry D'Almaine as Chicago district manager. Mr. D'Almaine will also handle the marine equipment business for ships' signaling, communication and lighting equipment on the Great Lakes.

Arthur D. Blanchard has been appointed to the industrial sales staff from the engineering department of the organization.

Decision in Lamp Suit to General Electric Company.—The suit of the Department of Justice of the United States against the General Electric Company and the Westinghouse companies operating under licenses granted to them by the former, in which the defendants were charged with violating the Anti-Trust Laws in marketing tungsten incandescent lamps, resulted in a decision in favor of the defendants early last month in the District Court of the United States at Cleveland. The Court said in part: "The conditions complained of have been in existence since at least March 1, 1912. The agency method of selling, as well as the license agreements in question, were not adopted until after they were submitted to the Attorney General of the United States for his information and consideration. They were neither approved nor disapproved; but defendants' later operations have been only after a full disclosure and during a period of prolonged silence. . . . . . .

"Such changes in methods of doing business as have been made since 1912 are in favor of freeing rather than restricting interstate trade. Other licenses have been granted, some thirteen in all. These other licensees and infringers have acquired a larger share of the total trade and the trade of the General Electric Company has diminished. It appears that its system is less costly and more economical to the consumer, has improved service to the customer, and has kept prices stationary if it has not reduced them in an epoch of rapidly rising prices. If the license agreement is stricken down, it does not free the Westinghouse Company or its business from any illegal restraint; it would leave the General Electric Company in exclusive ownership of the patents and would authorize, if it did not compel it, to take over the entire business of selling electric lamps having tungsten filaments. This result could be avoided only by depriving the General Electric Company of its patent monoply or making a new license agreement between it and the Westinghouse Company on terms to be fixed by the Court, and the right to do either is beyond the power of this Court."